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THESIS

A COMPARISON OF ENGAGEMENT RANGES FROM
THE M1A2 EARLY USERS TEST AND
EXPERIMENTATION TO THE JANUS(A) COMBAT
SIMULATION MODEL

by

Alfred Viana

September, 1992

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**A Comparison of Engagement Ranges from the M1A2 Early Users Test and
Experimentation to the Janus(A) Combat Simulation Model**

by
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Captain, United States Army
B.S., United States Military Academy, 1981

Submitted in partial fulfillment
of the requirements for the degree of

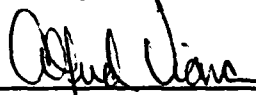
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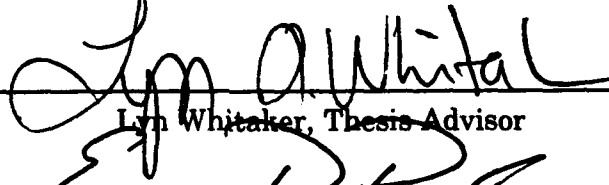
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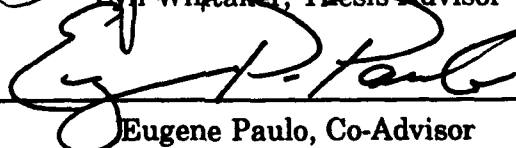


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ABSTRACT

The purpose of this thesis is to assist in the accreditation of the Janus(A) combat model for the post-test modeling phase of the Army's Model-Test-Model Concept. Specifically, the First Shot Engagement (FSE) and Opening Round Engagement (ORE) ranges from the September 1991 trials of the M1A2's Early Users Test and Experimentation are compared to similar ranges generated by the Janus(A) simulation model. The location and distributions of these ranges are compared using nonparametric procedures. A regression model using the results of the simulation model to predict the ORE range was developed and compared to the actual ORE ranges. The effects of the systematically varied test factors, such as a force's tactical posture and light conditions were also studied to determine if the simulation model could accurately predict their effects on the field test engagement ranges. An important conclusion of this thesis is that Janus(A) generates different engagement ranges than those observed in the September 1991 operational field test and that the model was unable to accurately predict the effects of the test factors.

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I. INTRODUCTION

A. RESEARCH OBJECTIVES

This thesis is part of the Model-Test-Model (M-T-M) research project sponsored by the U.S. Army Training and Doctrine Analysis Command-Monterey (TRAC-MTRY). The Model-Test-Model concept integrates operational field tests of weapon systems with combat simulation models. This thesis supports TRAC-MTRY's Model-Test-Model accreditation effort of the Janus(A) combat simulation model to augment operational field tests. Specifically, the focus of the thesis is to compare the opening round engagement (ORE) and first shot engagement (FSE) ranges from field tests to the ORE and FSE results from the Janus(A) high resolution combat simulation model.

B. BACKGROUND

With projected budget cutbacks, the operational test and evaluation community are looking to models and simulations to help reduce the cost of operational testing. The Model-Test-Model concept is an attempt to integrate simulation models and field tests to increase the efficiency and effectiveness of operational testing. High resolution combat models can provide the Army with the ability to support testing of new weapon systems by simulating the environmental and operational conditions under which the systems are tested. It must be proven that models and simulations accurately represent the weapon systems under investigation before the results are accepted as a part of the M-T-M.

In October 1990, Mr. Walter W. Hollis, Deputy Under Secretary of the Army (Operations Research) asked the TEXCOM Experimentation Center (TEC) at Fort Hunter Liggett, California to improve the Model-Test-Model methodology [Ref. 1]. TEC enlisted the help of TRAC-MTRY to conduct research in support of the M-T-M concept. TRAC-MTRY's research efforts are directed towards accrediting the Janus(A) high resolution combat simulation model. Accreditation is defined as the certification that a model is acceptable for use for a specific type(s) of application(s).

Initial research conducted by TRAC-MTRY compared tank engagement ranges from the Line of Sight-Forward-Heavy (LOS-F-H) Initial Operational Test (IOT) with Janus(A). The focus of this research was to analyze the feasibility of accrediting the Janus(A) model for post-test modeling by comparing tank first round engagement ranges. CPT Al East, in his thesis [Ref. 2], analyzed six similar trials of the fifty trials conducted. He concluded that:

Janus should not be accredited for post-test modeling of ground vehicle engagements because; 1) statistically significant differences in tank engagement ranges exist between Janus and the Line of Sight-Forward-Heavy Initial Operational Test; and 2) the test data were insufficient to support engagement range analysis of the Cavalry Fighting Vehicle or BMP.

His initial research indicated that tank engagement ranges are longer in Janus than the field test and that additional comparisons should be conducted to enhance both the model and field tests. Although this initial research effort compared tank engagements, the data collection effort from the field test focused on the Line of Sight-Forward-Heavy weapon system, not on the tank systems.

The opportunity to compare tank engagements between the model and a field test presented itself with the scheduled operational testing of the M1A2 tank. The M1A2 Early User Test and Experimentation (EUTE) was selected as the 'Proof of Principle' test case for the M-T-M concept. Several Army analytical agencies supported the pre-test modeling effort at TRAC-MTRY during the spring and summer of 1991. This team verified and updated the Janus(A) combat systems database, then conducted the M-T-M's pre-test modeling effort. Results of this effort were briefed to the operational testers (TEC) prior to the operational field test. TEC conducted the M1A2 operational test from August to December, 1991. Data collected from this operational field test focused on tank systems.

The M1A2 EUTE data collection effort focused on the operational capabilities of the M1A2 battle tank. This field test data included acquisition and engagement sequence data, crew-to-crew and tank-to-tank target handoff information, time sequence between a weapon system's acquisition to its engagement, and the type of engaging weapon system. This data collection effort of the M1A2 EUTE field test provided an excellent opportunity to accredit the Janus(A) high resolution combat model for the M-T-M concept.

The position locations of these weapon systems were converted into movement routes for use in a high resolution combat simulation model with the FHL terrain. Three replications of each trial were conducted to obtain engagement data.

This thesis compares the opening round engagement (ORE) and first shot engagement (FSE) ranges from the September 1991 M1A2 EUTE field trials with the

replicated Janus(A) runs. A secondary objective is to validate the initial research finding that Janus(A) ranges are longer than those from the field trials. This would suggest that lines of sight are longer in the model than in the field test, and suggest that a higher resolution terrain database is required to develop Janus(A) into an effective operational testing planning tool.

C. RESEARCH METHODOLOGY

The research for this thesis was accomplished in four major phases. First, the automated process to construct a Janus(A) movement file was modified. This process replicates the position locations of field test vehicle routes for use in the Janus(A) model. Second, Janus(A) was enhanced to duplicate a M1A2 tank system for use with the M1A2's Commander's Independent Thermal Viewer (CITV) algorithm. Third, computer programs were developed to automate the collection of opening round engagement data from the field test and the Janus(A) model. Fourth, a comparison between the test data and Janus(A) was analyzed using statistical procedures.

D. ORGANIZATION

This thesis is organized into six chapters. Chapter II describes the Model-Test-Model concept as it relates to the M1A2 Early User Test and Experimentation. Chapter III contains a description of the field test, limitations of field test data, and an analysis of the field test ORE range data. A discussion of the Janus(A) combat model and the methodology of converting field test data into a formatted Janus(A) file are given in Chapter IV. A description of the CITV algorithm and an analysis of the sample

Janus(A) data are also discussed in Chapter IV. Chapter V offers a comparison between the Janus(A) and the field test ORE and FSE ranges. A summary of findings and suggestions for future research are presented in the final chapter.

II. MODEL-TEST-MODEL

A. GENERAL

The successes achieved in the Persian Gulf were in large part due to the Army's six imperatives: quality force, confident and competent leaders, rigorous training, correct doctrine, the right mix of forces and continuous modernization. To ensure that our Army is equipped with extremely lethal, high quality systems that can be rapidly deployed to meet our national strategic goals and objectives, the Army must continually modernize its war fighting equipment. Modernization decisions made almost twenty years ago resulted in the "Big Five" weapon systems: the Patriot missile system, Apache and Black Hawk helicopters, Bradley fighting vehicle and the M1A1 Abrams tank. Today's weapons will not be suitable for tomorrow's battlefields; the modernization decisions made today are the key to success on the battlefield of tomorrow. Stephen Conver, the Army's Acquisition Executive states:

to achieve continuous modernization for each major class of equipment, we must adopt a budgeting strategy of active research and development along with either new production or major modification programs. Given that dollars are scarce, we must be careful that the programs in our budget are the ones that are most needed and most likely to succeed. [Ref. 3]

An independent operational test and evaluation (OT&E) is required prior to a full scale production decision during the acquisition process for both new production and major modification of an existing weapon systems. As the complexity and cost of testing

weapon systems increase, efficient and cost effective alternative methods are desired to enhance the decision maker's ability to test the critical operational system capabilities prior to a production decision.

Statistical method simulation is one of the most widely used operations research modeling approaches now employed by the government. Currently used in the evaluation of force mixture, doctrine, and weapon effectiveness, models and simulations can also contribute to operational tests and evaluations. With the use of computer simulations, inferences can be drawn without building, disturbing or destroying a physical system. By illustrating the necessary operational capabilities of a system, models and simulations can augment and complement actual field tests which are otherwise constrained by cost, security, safety, portrayal of threat capabilities, test instrumentation, treaty constraints, weather, maneuver space, representative terrain, and availability of system components [Ref 4:p. 1].

Operational field testing is indisputably the preferred primary data source (short of actual combat) for operational evaluations. Even as law precludes modeling and simulation as the sole data source for operational test and evaluation, there are areas within the OT&E process for which models and simulations can contribute to a more cost efficient and effective operational test and evaluation process. Modeling and simulation can contribute to test planning, test data analysis and evaluation to augment, extend, or enhance the test results. It contributes to the development of weapon system tactics along with employment techniques and early operational assessments of expected capabilities. Models and simulations can identify which elements of the system's performance

capabilities are important while considering the user's requirements and then enhance the test plan by focusing on those capabilities. Models and simulations can contribute to a more efficient and effective operational test and evaluation process.

B. MODEL-TEST-MODEL (M-T-M) CONCEPT

The Model-Test-Model (M-T-M) concept is designed to exploit both the combat simulation modeling and field testing capabilities of the U.S. Army analysis agencies. The concept of Model-Test-Model, although not rigidly defined, is to perform pretest combat simulation modeling prior to field testing in an effort to gain information useful in designing a field test (model), obtain the results of the field test (test) and then fine tune the model/simulation for accreditation. Once accredited, the model is used for future extrapolation and interpolation (model). The model provides insights into whether test objectives will be met, and if not, how the test design should be changed to emphasize the system performance capabilities. Upon conclusion of the field test, an accredited model can be used by the organization for cautious interpolation and extrapolation.

There are three main phases in the Model-Test-Model concept: pretest modeling, field test, and post-test modeling and calibration. In addition to these three main phases, two additional phases have been recently proposed in the M-T-M concept: long-term planning and accreditation [Ref 5:p. 3].

1. Phase 0 (Long-term Planning)

Phase 0 begins with an agreement between the analytical and operational test organizations to identify resource responsibilities. During this phase, a Memorandum of

Agreement (MOA) and a Project Coordination Sheet are signed by the participating organizations to identify responsibilities for resource commitments, working relationships and product expectation.

2. Phase I (Pretest Modeling)

This phase uses high resolution combat simulation models to help plan field tests. These field tests include Force Development Test and Experimentation (FDTE) , Early Users Test and Experimentation (EUTE) and Initial Operational Tests (IOT). In conducting simulations with different force sizes, scenarios, terrain, and tactics, the modeler uses techniques such as response surface methodology (RSM) to make recommendations for improving the operational test design in terms of measures of performance (MOP) and measures of effectiveness (MOE) relevant to the operational tester. Replicating the field test site terrain in the simulation model provides the pretest modeling team invaluable insight on the effect of terrain in evaluating weapon systems and tactics.

By the direction of the Operational Test and Evaluation Command (OPTEC), the Army's M-T-M concept supported the M1A2 battle tank's EUTE, making it the 'proof of principle' base case. Subject matter experts (SMEs) from the U.S. Army Armor Center, Test and Experimentation Command (TEXCOM) Armor Directorate, TEXCOM Experimentation Center (TEC) Threat Office along with personnel from the Training and Doctrine Analysis Command, Monterey (TRAC-MTRY) were involved in the EUTE scenario development and test design for the M1A2 tank. TRAC-MTRY conducted over 100 computer simulations of the base scenarios during the M-T-M pre-test phase. They

briefed their analysis and conclusions to the Director of TEC for possible modification to the EUTE test design. These results included recommendations to improve the test design and scenarios. [Ref. 6]

3. Phase II (Field Test)

During this phase, operational effectiveness and suitability of the weapon system is evaluated. Field testing is usually conducted in two phases. The first phase is an early test to determine if doctrine and/or tactics are at issue and usually referred to as a Force Development Test and Experimentation (FDTE) or an Early Users Test and Experimentation (EUTE). The second phase is an Operational Test (OT) to determine the operational effectiveness of the weapon system. Operational effectiveness is the overall degree of mission accomplishment of a system used and supported by representative personnel in the environment planned or expected for operational employment. During the force development testing, player units replicate successful battle tactics developed by the maneuver unit leaders during the pre-test modeling phase. To increase the credibility of the operational test, during the operational test tactics are unscripted. Although constrained by terrain limits, force size and operational requirements, maneuver units are free to use tactics as they would realistically employ. The operational tests are conducted,

under realistic combat conditions, of any item of (or key component of) weapons, equipment, or munitions for the purpose of determining the effectiveness and suitability of the weapons, equipment, or munitions for use by typical military users. [Ref. 7]

The operational field tests, usually consisting of a series of Force-on-Force (FOF) battles, are conducted by military personnel to replicate the realistic employment of the system related to issues of lethality, fightability, survivability, and suitability.

It is important that during this phase, the modeler observes the field test to understand the conduct of the test, then coordinates with the data reduction group to understand the collection methodology and format of the test data. Upon completion of the field tests, the modeler obtains the necessary data to begin the post-test modeling phase.

4. Phase III (Post-Test Modeling and Calibration)

During post-test modeling, the objective is to refine or calibrate the simulation/model in preparation for accreditation. Model input parameters such as weapon system characteristics, weather data, ammunition basic load, visibility conditions, type and number of participating vehicles, and other field test parameters are evaluated, verified and updated. Post-test modeling is the iterative process of calibrating and examining the model/simulation until it converges to a specific tolerance limit.

The specific tolerance limit is defined as that level in which the decision maker, usually the agency responsible for accreditation of the model/simulation, believes the model/simulation is an accurate representation of the portion of reality under study. The criteria for distinguishing between an "acceptable" representation of reality and an "unbelievable" representation are difficult to determine. Models and simulations are inherently approximations of reality and hence never true; "...the inductive inference must be conceived as an operation belonging in the calculus of probability." [Ref. 8] Since

the model/simulation will never exactly match the field test, nor the field test actual battle, a multistage approach is required in which to set the tolerance limit at an acceptable level.

Accreditation focuses only on representing a specific system. Two approaches are available in which to accredit a model. The first approach is a micro approach which analyzes individual events, while the macro approach compares the overall outcome of the field test with that of the model.

a. Micro Approach

The micro approach of comparing the model to the test is the primary approach recommended by CPT Bundy of TRAC-MTRY [Ref. 8:p. 6]. The model/simulation replicates actual player states such as movement routes, orientations of weapons systems, vehicle silhouettes, and vehicle movement rate. Parametric and nonparametric statistical methods are used to compare the field test data with Measures of Performance (MOP), such as the distribution of detection ranges, interdetection times, trigger pull ranges, first shot engagement ranges and proportion of targets detected which result in engagements.

b. Macro Approach

In the macro approach, the number of units and their initial positions are established, general movement routes are provided and then the model is run. Comparison of the model output to the field test is conducted using measures of performance comparable to the Critical Operational Issues and Criteria (COIC) of the

weapon system. These critical issues may include: Can the M1A2 defeat the Future Threat Battle Tank? Is the new weapon system more survivable than a comparable or the replaced system? Suggested MOPs for this approach include the percentage of forces remaining over time, the number of shots fired over time and force loss exchange ratios.

Finally, the macro and micro analyses are combined in an attempt to accredit the model. The modeler combines the micro and macro approaches by replicating individual player states and comparing the results using either approach or a combination of both approaches.

5. Phase IV (Accreditation or Validation)

This phase involves the validation or accreditation of the model by the end user of the model. Accreditation is the "approval by management, based on experience and expert judgement, that a model is adequate for its intended use." Validation, is the process of determining "that a model is an accurate representation of the intended real-world entity from the perspective of the intended use of the model." [Ref. 9] While full validation of Janus(A) may be difficult to achieve, accreditation for use with a specific system, such as the M1A2, is possible.

This thesis is a continuation of TRAC-MTRY's Model-Test-Model accreditation effort of the Janus(A) simulation model with specific focus on the M1A2 tank. The focus of the thesis is to compare the opening round engagement and first shot engagement ranges of an actual field test of an enhanced weapon system with the Janus(A) combat simulation model.

III. OPERATIONAL FIELD TEST

A. BACKGROUND

The Abrams M1A2 tank, an enhanced version of the M1A1, is a full-tracked, low profile, armored, land-combat assault weapon system. It was designed to defeat threat tanks through the year 2000 due to its increased fightability, lethality, and survivability. The enhancements of the M1A1 Abrams tank include a Commander's Independent Thermal Viewer (CITV), a Position Navigation System (POS/NAV), increased ballistic protection, an Improved Commander's Weapon Station (ICWS), and other state-of-the-art electronics and ammunition technology. Figure 1 shows the key new features of the M1A2 battle tank.

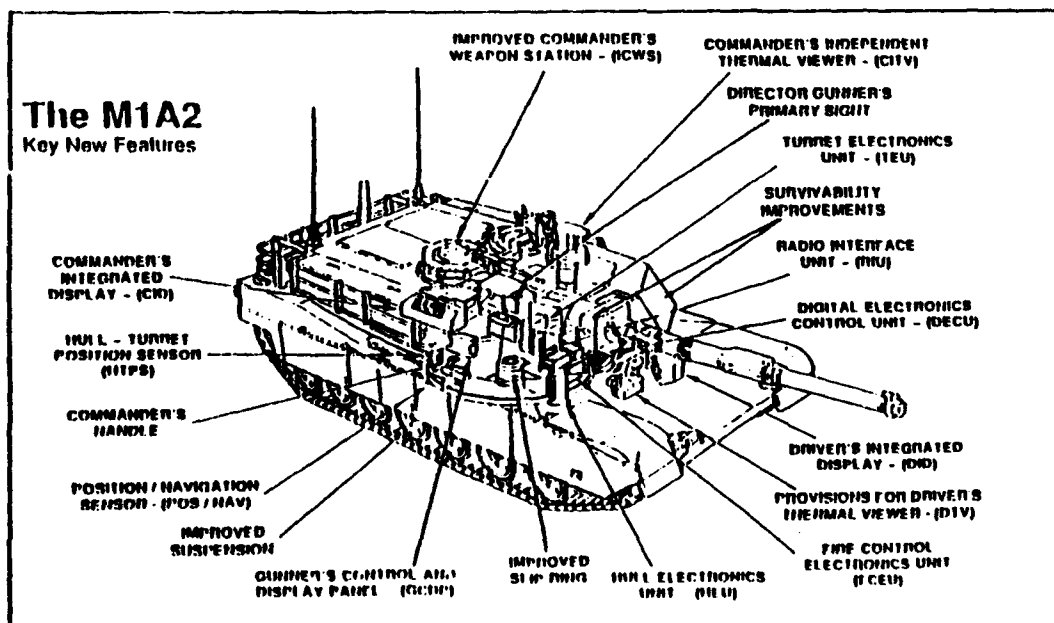


Figure 1 M1A2 Battle Tank

The primary feature of the M1A2 is the CITV which offers the tank crew a "hunter/killer" acquisition capability. The CITV enables the commander to search for targets independently from the gunner, yet still direct the firing of the main tank gun.

The purpose of the M1A2 Early Users Test and Experimentation (EUTE) was to evaluate the operational effectiveness and suitability of the modifications made to the Abrams M1A1 tank to support the Army's low rate initial production decision. The EUTE had four issues, all critical:

- Can it defeat the Future Soviet Tank II?
- Is the fightability of the M1A1 improved when upgraded?
- Is the M1A2 more survivable than the M1A1?
- Is the M1A2 operationally suitable?

The test was designed to evaluate one platoon of M1A1s and one platoon of M1A2s. The Testing and Experimentation Command (TEC) conducted the test at Fort Hunter Liggett, California from 28 August 1991 to 16 January 1992. The test was conducted in six phases: I) crew training; II) tank gunnery; and III) the operational mission summary (OMS). Phases IV through VI repeated phases I through III with rotated crews. Phase III, conducted in September, consisted of sixteen force-on-force field trials. Each blue platoon of four tanks conducted two 48-hour operational mission summary (OMS) or force-on-force field exercises. The operational mission summaries consisted of four scenarios or missions: 1) a meeting engagement; 2) a hasty defense; 3) a deliberate defense and, 4) a deliberate attack. The EUTE systematically varied test factors and conditions which influenced the operational effectiveness measurements. These factors

included the tank system (M1A1 versus M1A2), light conditions (day versus night) and tactical posture of the unit (offense versus defense). The meeting engagement and the deliberate attack were considered offensive maneuvers, the hasty and deliberate defense were defensive maneuvers. Eight trials were conducted with the M1A2. Four trials were conducted at night with the M1A1 and four with the M1A2 tank. Blue forces were in an offensive scenario for eight trials and a defensive scenario for eight trials. The tactical posture factor was not balanced for the red force which had twelve offensive scenarios and four defensive scenarios.

Each trial was a force-on-force battle between a blue force of four M1A1 or M1A2 tanks and a red force of varying size depending on the mission scenario. The size of the red force varied to reflect the doctrinal mission force ratio. The red force varied in size from one to four Future Soviet Tanks (FST) and one to seven armored personnel carriers (BMP2). As an example, a three to one force ratio advantage was desired for a blue deliberate attack mission. Since the blue force size remained constant at four tanks throughout the EUTE, the red force consisted of only one FST and one BMP. The red forces included helicopters in four trials, two for the M1A2 trials and two for the M1A1 trials. The M1A1 tank and the Cavalry Fighting Vehicles (CFV) were surrogates for the FST and BMP2. The trials lasted approximately one hour in length.

B. TEST DATA

1. Data Source

The TEXCOM Experimentation Center provided data from the field test for the sixteen trials. The files included both vehicle position location files (PLS) and operational mission summary (OMS) files. The PLS files provided the identification and location of the individual systems for every second of play. These files were used to create the deployment and movement route files required by JANUS(A).

The data from the OMS files were used to compare the JANUS(A) and the field test. The OMS files were separated into the two opposing forces with the following file extensions ".TAS" and ".RED" for the blue and red forces, respectively. These files contained information such as the time of detection, range and identification of both the acquiring and acquired system, *method of detection, engagement hand-off sequence*, engaging system identification, time of engagement and range of engagement. Each recorded observation in the red (.RED) OMS file was a red engagement sequence. Recorded observations in the blue (.TAS) OMS file were either blue engagements or through-sight intervisibility sequences between the opposing force vehicles.

The OMS data fields contain information from numerous sources. These sources included both automated systems and visual inspection of video recording of the trials using through sight video cameras mounted on the tanks. If an engagement sequence did not obtain a laser pairing, video recordings were used to identify the vehicle. Vehicles identified as either a tank or a personnel carrier were recorded with an "XX" extension when the vehicle identification number was unknown or unreadable. Vehicles

that could not be identified as either a tank or a personnel carrier were recorded as "UNK".

Observations with "88:00:00" in the engagement time field did not occur and no engagement range was recorded. "99:00:00" observations were defined as an unknown occurrences [Ref. 10]. Numerous "99:00:00" observations included an engagement range, but have unknown times of engagement.

2. Data Limitations

a. Position Location Errors

The range measuring system (RMS) at Fort Hunter Liggett recorded the instrumented weapon system's position locations during the trial. RMS computed the range between a firer and target in a detection or engagement sequence using Pythagoras' theorem. Some of the ranges might not have been totally accurate, due to occasional errors in determining position location.

The three main errors associated with position location data were jitter, gaps and spikes. Jitters are small position errors caused by a triangulation error in the RMS, usually seen as a stationary vehicle that appears as moving within a small radius in the RMS position location file. Spikes are large position errors also caused by occasional triangulation errors, usually seen as a vehicle that moves a great distance from the last recorded position. Gaps are losses due to a system moving into an area in which the RMS cannot obtain a signal.

b. Unknown Ranges

During the operational field test, weapon systems were instrumented with lasers and laser sensors. When a laser beam was fired in the direction of the aimpoint, the firer's identification was recorded. If another system's sensor detected a laser shot, the system's identification was also recorded and the RMS calculated the range. If a laser was not received by a target, the RMS did not calculate range and an unknown range was recorded. There were numerous factors which contributed to unknown ranges. These factors included: missing a target, improper laser boresighting, improper use of sensors, attenuation of laser beam, insufficient power, and buffer overload [Ref. 11].

3. Data Selection

a. Analysis of Field Data

During the sixteen trials, there were 467 blue force detection and engagement observations and 382 red force engagement observations in the OMS files. In the .TAS file, each record consisted of an identification segment, acquisition segment, target handoff segment, termination of engagement segment, engagement segment and an assessment of engagement segment. The .RED record included an intervisibility segment, acquisition segment, engagement segment and an assessment of engagement segment. Ninety-three of the blue and twenty-six of the red observations were coded as not occurring with a "88:00:00" in the engagement time field. The red file recorded one hundred and one "99:00:00" records in the engagement time field, while the blue recorded no "99:00:00" observations. These observations were used for the data analysis if an

engagement range was recorded and the weapon system did not have a recorded engagement range for the trial. If a vehicle recorded an engagement range with a time mark, this observation was used to determine ORE. If no time mark was recorded, but a "99:00:00" recorded a range, this data point was used. We assume the longest range is the ORE range. Table I shows the trial number, number of weapon systems, number of recorded engagement range observations and number of total engagements. The difference between the number of known engagement ranges and total engagements is a result of the unknown ranges discussed previously. The UNK column in the table represents the number of blue tank engagements in which a red system could not be identified. The number in parentheses represents the fratricide engagements. The blue side consisted of only blue tanks. The blue columns indicate which weapon system the blue tanks are engaging, the red columns show which weapon system is engaging a blue tank.

A crosstabulation of the engagement observations for both the blue and red side is shown in Table II. The table shows the weapon system's number of recorded engagement ranges and, in parentheses, the total number of engagements against the opposing force's weapon system. Excluding helicopter engagements, the blue force recorded 246 engagement ranges. Approximately twenty-two percent of the total blue engagements were obtained from the video recordings where the weapon system can be identified, but not its identification number; no engagement range was recorded for these observations. The blue side recorded two fratricide engagements, one with the M1A1 and one with the M1A2. The red side recorded 168 engagement ranges. Seven percent of

Table I EUTE OBSERVATIONAL DATA BREAKDOWN

Early Users Test and Evaluation Engagement Summary (M1A2 vs M1A1)										
	RED FORCE SIZE			Blue Tanks Engaging Red System				Red System Engaging Blue Tank		
TRAIL	BMP	TANK	HELO	BMP	RTNK	HELO	UNK	BMP	RTNK	HELO
269A*	7	4	0	0/0	0/0	1/0	0	0/4	5/7	0/0
274A1	6	4	0	16/30	10/17	0/0	1	4/17	6/14	0/0
273A	2	3	0	0/0	1/1	0/0	0	7/8	10/25	0/0
281B	1	1	0	4/4	1/1	0/0	1	0/2	9/10	0/0
273B	6	3	0	32/43	20/20	0/0	5	21/50	2/3	0/0
281A	7	4	4	2/3	9/10	0/0	9	2/9	7/7	0/7
273C	1	1	0	13/15	13/13	0/0	6(1)	12/23	6/8	0/0
280A	2	3	2	5/7	2/18	1/1	18	1/4	3/4	1/29
264C	8	4	0	37/45	16/39	0/0	5	0/0	1/6	0/0
271A	6	4	0	16/30	10/17	0/0	9(1)	4/17	6/14	0/0
264A	7	4	3	3/7	1/2	7/21	1	0/1	5/7	0/5
270B	8	4	0	3/14	9/17	0/8	10	11/16	1/5	0/1
270A	2	3	0	0/0	0/0	0/0	4	0/4	5/7	0/0
280C	1	1	0	3/3	3/3	0/0	0	0/18	2/3	0/0
263A	2	4	3	12/13	3/3	0/0	0	2/2	7/12	0/0
270C	1	1	0	16/16	0/0	0/0	0	6/7	4/70	0/0

* Trail 269A Only 3 M1A2 in Trail
 Known Engagement Range/Total Number of Engagements
 UNK were shots fired at a target that could not be identified.
 (X) Fratricide Shots

the total red engagements were with unidentified blue systems. The red OMS file also contained one fratricide engagement.

b. Opening Round Engagements

Approximately 75% of the field test data records for engagement ranges are either unknown, did not occur, or are multiple engagements. A multiple engagement is defined as a weapon system firing at the same target within a specific short time

Table II BLUE AND RED ENGAGEMENT CROSSTABULATION

Crosstabulation of Blue Shooting @ Red Systems				
Blue Tanks	Red Systems			
	BMP	FST	HELO	Blue Tank
M1A1	90 (128)	44 (83)	7 (29)	1
M1A2	61 (79)	51 (75)	1 (1)	1

Crosstabulation of Red Shooting @ Blue Systems			
Red Systems	Blue Tanks		
	M1A1	M1A2	FST
BMP	37 (88)	39 (114)	0
Helicopter	34 (64)	45 (73)	0
FST	0 (6)	1 (36)	1 (1)

(XX) Total number of observations
Blue force had 71 UNK engagements

interval. Multiple engagement ranges are considered to be statistically dependent. During field trials, the RTCA system determines whether the engagement represents a missed shot, a mobility kill or a system kill by using a random number draw from a tabulated probability distribution. The decision to fire a sequential round is then conditioned upon the outcome of this random draw. This second, or multiple engagement, is dependent on the preceding round's effectiveness.

In the field test, a weapon system's engagement sequence is a function of the tank crew's ability to detect a target and then perform the necessary tank or armored vehicle gunnery tasks to engage that target. We assumed that crews engaged targets at the first opportunity because of the high correlation between the recorded

acquisition range and the subsequent engagement range. The "trigger pull" in the field test is not a random number draw, but rather a physical phenomenon that depends upon the system crew's capability. It is a binomial event indicating that LOS exists and the crew has decided that conditions are favorable to engage a target. Thus, to reduce the dependence inherent in multiple engagements, first shot engagements and opening round engagements were used to analyze the field test with Janus(A).

An opening round engagement (ORE) is defined as the initial or opening shot of a tank against an opposing vehicle. For example, if Blue forces have four tanks and Red forces have three vehicles, there are twelve possible opening round engagement opportunities for the Blue forces, each of the four tanks engaging the three different vehicles. We assume that each weapon system initially searches for targets independently. While OREs do not ensure independence, they provide a better response variable than all recorded engagements. A subset of the ORE is the first shot engagement (FSE) range. FSE is defined as the first shot of a trial for each side. There are only two first shot engagement ranges for each trial, one per side.

Although the red forces used helicopters in four trials resulting in forty-one red and forty blue engagements being recorded, the test concept paper stated, "air, indirect fire, EW, and obscurant will not be included." [Ref. 12] Therefore, helicopter engagements are not considered in the analysis.

c. ORE Sample Size Analysis

Table III shows the median, interquartile range and number of OREs for the different trials and test factors. Blue force opening round engagements were recorded

for fifteen of the sixteen trials. Trial 269A recorded no blue engagement observations and only three red engagements. Trial 273A recorded only one blue ORE observation and four trials recorded only two observations. Red force opening round engagements were recorded for all trials, although trial 280C recorded only one red engagement. Trail 264C recorded only two observations. The spread of the ORE ranges is not constant between trials nor does the spread increase as the median ranges increase.

The greatest difference between the blue and red median ORE range is in trial 273B. This trial also recorded the largest interquartile range of ORE ranges. During this trial, the M1A2s are in a defensive posture and their initial engagements are at ranges in excess of 3500 meters. The red force does not return fire until almost five minutes later and then at a shorter range, 1715 meters. This large median for the M1A2s is almost twice as large as the median ORE range from trial 281A which had the same test conditions.

Other unusual observations came from trial 270B. The blue median ORE range for trial 270B is almost three times as large as the other three median ORE ranges for the trial with the same test conditions. The blue force also recorded a larger interquartile range. The blue force, again in the defense, engages the red force at 2100 meters and then again at 500 meters. The red force does not return fire until almost five minutes after the first blue engagement, and then at a range of 1100 meters. Both trials indicate that the defensive force initially remained undetected while acquiring and engaging the opposing offensive force.

Table III EUTE OPENING ROUND ENGAGEMENT SUMMARY

Opening Round Engagement EUTE Results									
Tank	Offense (blue)	Day/ Ngt	Trial	Blue Force			Red Force		
				Median	IQR	OREs	Median	IQR	OREs
M1A2	OFF	DAY	269A			0	362	234	3
			274A1	2011	478	7	1624.5	921.5	4
		NGT	273A	1901	0	1	1900	304.5	8
			281B ¹	423.5	363	2	913	1885	3
	DEF	DAY	273B	3417	3083	17	323	630	5
			281A	1385.5	991	8	507.5	923	6
		NGT	273C ¹	1636	1021	3	1674	517	6
			280A	1118	1715	4	1716	1206	3
M1A1	OFF	DAY	264C	871	245	16	970	757	2
			271A	666	212	12	1377	1368	6
		NGT	264A	378	165	2	438	442	4
			270B	1084	1710	8	370	1045	3
	DEF	DAY	270A	1576.5	837	2	1973	546	9
			280C ¹	2459	431	3	2398	0	1
		NGT	263A	754	86	7	677	123	7
			270C ¹	1197	62	2	1060	196	5

¹ Red Force in a Defensive Posture, otherwise in the Offense

IV. JANUS(A) COMBAT MODEL

A. INTRODUCTION

Janus(Army) Version 2.0 is an interactive, closed, stochastic ground combat simulation. The simulation model, developed by the U.S. Army TRADOC Analysis Command at White Sands Missile Range (TRAC-WSMR), is primarily used as an analysis tool in support of Cost and Operational Effectiveness Analysis (COEA), tactics and doctrine analyses, and other Army studies. Janus(A) has the potential for additional training applications such as a Company level trainer and use in the Model-Test-Model concept. Janus(A) models individual systems moving, searching, detecting, and engaging on a user selectable three dimensional terrain representation. Some of the major functional areas simulated by Janus(A) include movement routes and speeds, search and detection, direct and indirect fire engagements, and obscuration. The simulation allows up to 600 units per side, each appearing as an individual symbol on a computer graphics display. These units contain one or more weapons systems such as the main tank gun or a machine gun. The model user inputs operational weapon characteristics of the weapon system. These characteristics include the direct fire weapon's effect (Probability of Hit/Kill), optical and IR detection sensor capabilities, movement speeds and capabilities and ballistic protection.

The Janus(A) simulation uses the Night Vision Electro-Optical Laboratory (NVEOI) detection algorithm to determine Line of Sight (LOS) calculations [Ref. 13]. The

weapon system's characteristic parameters are used by the model to determine detection and direct fire engagements. For example, if a weapon system has line-of-sight (LOS) to a target, detects a target, has ammunition, and is not in a hold fire status, an engagement event occurs. The outcome of this engagement sequence is a stochastic event. Each weapon/target combination is assigned a probability of hit (PH) and probability of kill (PK) which are functions on such factors as range, weapon/target movement, weapon/target orientation, and range. The PK and PH are multiplied to form a Single Shot Kill Probability (SSKP) which is used to generate a random draw to determine hit or miss.

Janus(A) uses the three dimensional terrain profile to determine if a geometric line-of-sight exists between any two combatants. The line-of-sight calculations are a function of the terrain, weather, obscuration, and target size. Janus(A) provides standard terrain resolution at 12.5, 25, 50, 100, and 200 meter terrain grids. 50 meter terrain resolution was used for this effort to replicate the field test movement routes. At the fifty meter terrain resolution, Janus(A) uses the digitized terrain data base to obtain elevation readings at fifty meter intervals and then interpolates the elevations between these points.

B. CONVERSION OF FIELD TEST DATA

In an attempt to reduce the effect of terrain between the actual field test trials and the Janus(A) simulation runs, the FHL fifty meter terrain resolution area was used in the post-test model analysis. TEC provided a vehicle position location (PLS) data file for the sixteen field trials from the RMS. This file provided a vehicle's grid location for every

second of the field trial. Two FORTRAN programs converted these PLS files into Janus(A) movement route files for each minute of field trial play. Thus, the actual force structure and movement route of the vehicles in the field test were duplicated in Janus(A).

The two conversion programs are INITNTC and PLS3. INITNTC is a FORTRAN program which originally converted data from the National Training Center (NTC) into Janus(A), Version 1.5 format. A Fortran program written by CPT Al East, PLSTRN, converts FHL position location data (PLS) into a NTC format. This converted file is then converted into Janus(A), Version 1.5 format using the INITNTC program. With the Janus(A) upgrade to version 2.0 and the decision to conduct M1A2 Janus(A) runs with the Commanders Independent Thermal Vision (CITV) algorithm, an updated version of the PLSTRN program, renamed PLS3, was written to convert the EUTE FHL data into a Janus(A) formatted file. A copy of the program is attached in Appendix A. This new program converts the field position data into a data file for the INITNTC conversion program. The program was used for both the M1A2 and M1A1 FHL position location files to build the necessary Janus(A) formatted movement and deploy files.

Janus(A) Version 2.0 contains the OBSTREDO conversion program to convert the Janus(A) Version 1.5 into 2.0 format. The OBSTREDO.EXE program is in the JADM.MAK directory and converts both the DPLOYXXX.DAT and JSCRNXXX.DAT file into the new version format. For the M1A2 trials, the CITV algorithm is used to model the M1A2 tank with its independent sensor. An additional conversion program, FIXUPJSCRN, is required to "mount" the tank commander (tank system one) on the gunner's tank (tank system two).

C. MODEL PREPARATION

During the pretest phase, TRAC-Monterey collected input parameters for the M1A2 from: 1) Concepts Analysis Division, Directorate Combat Developments, Armor Center; 2) Army Material systems Analysis Agency; 3) TRAC Studies Analysis Center; and 4) TRAC White Sands. These parameters were used to update the characteristic data files in Janus(A). The pretest modeling team developed an improved terrain database by modifying the terrain characteristics of FHL terrain files and developed a night database with the appropriate weather and sensor data.

1. Modification of Player States

In the Janus(A) display, a vehicle's movement route is displayed on a graphical display with triangular nodes. These nodes represent the actual movement route of the field vehicles. The INITNTC program provides the file, TIMENODES.DAT, which links a time mark with each node. This file is used to "synchronize" the Janus(A) battles using stop nodes. If a vehicle advanced faster than the other vehicles in the force, a timed stop node was used to synchronize his movement with the main force.

Because actual vehicle routes were replicated in Janus(A), some vehicles were killed at longer ranges in the field trial than in the model. This 'kill' caused a Janus(A) vehicle to stop at that location. To ensure that vehicles would continue to advance in the model, one additional node located at the opposing forces last position was added for each vehicle. Thus, a vehicle's movement route was modified and extended from the last known location to the opposing unit's location.

A vehicle's line-of-sight (LOS) and field of view can be displayed on the display terminal. Vehicle location modifications were also considered to defensive forces located in positions with no line-of-sight. These vehicles were moved within a 25 meter radius of their original position to a location providing line-of-sight to the opposing forces route of march. This is an acceptable modification because defensive forces are employed in tactically sound positions, taking advantage of the natural concealment provided by a tree line. The PLS data file then located a vehicle in a Janus(A) wooded area and thus restricted LOS to an opposing force's avenue of approach. All vehicle fields of view were orientated toward the general direction of the opposing force.

2. Modeling M1A2 with the CITV Algorithm

The CITV provides the M1A2 tank system with an additional independent thermal sensor, allowing both the commander and the gunner to acquire targets. Since there existed no capability in Janus(A) to create a system that uses two independent sensors and merge their target list, Major Jim Hoffman, Military Analyst at TRAC-MTRY, developed the CITV algorithm. This algorithm builds an integrated target detection list from the two independent weapon sensors. Two independent sensors are modeled in Janus(A) by mounting a system on another system. The M1A2 was modeled in Janus(A) as a tank "riding piggy back" on another tank system. The effect of this algorithm is that both the gunner and commander's thermal/optical sight system can independently search different sectors of the battle field and then "communicate" their detection information prior to target engagement.

D. JANUS ENGAGEMENT DATA

1. Collection and Reduction

Due to the time required to convert the sixteen field test trials into Janus(A) version 2.0 format and run the trials, only three runs per trial for a total of forty-eight Janus(A) simulation runs were conducted.

The Janus(A) Analyst Work Station (JAWS) direct fire file was used to collect engagement ranges. Several FORTRAN programs were written to create the blue and red opening round engagement range ASCII files and the first shot engagement ASCII files. The FORTRAN program JANUS.FOR uses the Janus(A) Direct Fire Report and computes the ORE. Two programs are used for the actual field trials; ACQ2.FOR is used to convert the FHL OMS files into a format that the FORTRAN program FLD.FOR uses to compute the OREs. A copy of these programs is attached in Appendix B.

2. ORE Sample Size Analysis

Table IV shows the median, interquartile range and number of OREs for the different Janus(A) trials and test factors. Although all Janus(A) trials recorded OREs, not all runs recorded OREs. There were 307 blue and 276 red opening round engagements in the forty-eight Janus(A) trials.

Blue forces in trial 281B recorded only two OREs during the three runs, the second run recorded no blue engagements. The red side recorded fourteen total engagements. Trial 269A recorded the greatest interquartile range for both sides with the blue force in a defensive tactical posture. LOS between the forces existed from

Table IV JANUS(A) OPENING ROUND ENGAGEMENT SUMMARY

Opening Round Engagement Janus Trials									
Tank	Offense (blue)	Day/ Ngt	Trial	Blue Force			Red Force		
				Median	IQR	OREs	Median	IQR	OREs
M1A2	OFF	DAY	269A	1882	2574	38	498	2533.5	28
			274A1	369	431	20	381	462	16
		NGT	273A	1881.5	521	22	2031	448	29
			281B ¹	1914	239	2	1180	1527	14
	DEF	DAY	273B	2051	1064	25	1468	1577	9
			281A	1604	322.5	44	1705	586	29
		NGT	273C ¹	1867	108	4	1946	121	17
			280A	1419	427	7	839.5	462	16
M1A1	OFF	DAY	264C	438	654	13	578	639	12
			271A	1544	596	25	236	521	6
		NGT	264A	1053	133	31	1015	75	13
			270B	1123	607	33	970	328	9
	DEF	DAY	270A	1897	1359	17	2118	72	31
			280C ¹	1531	322.5	5	1724	907	17
		NGT	263A	924	314	6	563	541	19
			270C ¹	1216	284	15	1389	1323	11

¹ Red Force in a Defensive Posture, otherwise in the Offense

simulation time zero to twelve minutes and again at simulation time twenty-two minutes until the end of the battle. This resulted in a bimodal distribution of the ORE ranges for this trial. The bimodal peaks occurred at an average range of 220 and 2300 meters.

Trial 271A's blue median ORE range was almost three times as large a similar trial's median ORE range. The red force did not return fire until approximately five or six minutes after the blue's initial engagement. The blue's initial engagement range was between 1500 and 1800 meters while the red engaged initially at 800 meters. Initial engagements for trial 264C, the trial with similar conditions, were 900 meters and the median ORE range was 438 meters.

V. COMPARISON OF ENGAGEMENT RANGES

A. GENERAL

The purpose of this analysis is not to determine whether the M1A2 is superior to the M1A1, but rather to conduct a comparison of the JANUS(A) combat model with an actual operational field test. The primary approach to model accreditation is the micro approach. The field test player states are replicated in Janus(A) and several Measures of Performance are used to compare the model to the field test. Perhaps the most significant measure of performance is how the distribution and location of the field test compare to those of the Janus(A) model. Both the modeler and the acquisition community benefit from these comparisons. The modeler is provided actual data from field trials to refine and update the model's algorithms and data base; while the acquisition community gains trust in the model's representation of the weapon system's operational capabilities. This benefits the decision makers by increasing their confidence in the model for extrapolation purposes. This thesis narrows the analysis to the FSE and ORE ranges to compare the M1A2's EUTE trials to the Janus(A) model using parametric and/or non-parametric statistical procedures.

B. MEASURES OF PERFORMANCE

Both the FSE and ORE ranges are used to compare the model with the field test. With the increased lethality of today's weapon systems, the first shot usually determines

who survives and who dies on the battle field. The FSE range is the first time in a trial when a weapon system has met all the conditions for an engagement sequence. It is the time in which a force detects, acquires and then consciously engages an opposing force by pulling the trigger. This range is also an indicator that LOS exists between the forces. While the FSE range indicates the initial LOS distance, the ORE range is a relative indicator of the flow of the battle. The ORE range is the first time a weapon system has met the conditions to engage an opposing system. Another important indicator of how well the model replicates the field test is what effects the test factors have on the weapon system. During the pre-test modeling phase, the M-T-M concept is used to determine which factors are important in the experimental test design. These test factors are then used in the design of the operational test to stress the weapon system. The following MOPs were used for the comparison:

- Paired two sample test of the FSE range
- Evidence of correlation between model and field test for the FSE range
- Janus(A) predictability of the field test's FSE range
- Paired two sample test of the ORE Median, Maximum and Interquartile Range
- Comparison of the Distributions and Medians of the ORE range
- Comparison of the statistically significant test factors.

The FSE range comparisons are general comparisons of the field test to Janus(A) model.

The ORE range comparisons are a detailed comparison as it compares the 'flow of the battle' versus only the first engagement of a battle. The comparison of the test factors

is used to indicate whether the M-T-M pre-test modeling phase accurately predicted the significant systematically varied test factors.

The statistical software package, STATGRAPHICS, was used for the statistical analysis. Because of the relatively small sample size within each trial, a significance level of ten percent was chosen.

C. ASSUMPTIONS

The ORE and FSE observations are assumed to be independent within each trail and between trials. The reason for analyzing the ORE ranges instead of all engagement ranges is to improve the tenability of assuming independence within the trial. Normality of the ORE range trial samples was checked using the Kolmogorov-Smirnov and the Chi-Square Goodness of Fit tests. In general, the ORE range samples are not normally distributed and the ORE sample size within a trial is relatively small. Since there is serious doubt of the normality assumption, mostly nonparametric methods were used in comparing the field test samples to the Janus(A) simulation runs. Each of the forty-eight Janus(A) runs used different initial seed values for their random number generators and the same initialization rules, which implies that comparable random variables from the different runs are independent, identically distributed [Ref. 14:p. 529]. The field test movement routes and terrain were replicated in Janus(A), hence the paired comparisons. However, given a particular scenario (i.e. movement routes and terrain) the field test and Janus(A) results are independent.

D. FIRST SHOT ENGAGEMENT RANGE ANALYSIS

The first MOP uses a paired ranking of the FSE range and is probably the most general comparison between the field test and Janus(A). The Wilcoxon signed ranks test was used to compare the thirty-one FSE ranges from the field tests to the Janus(A) runs (note: Trial 269A had no blue field test observations). Six paired tests were conducted, three for the one blue field test against the three Janus(A) runs and three for the red side. Five tests resulted in p-values ranging from .81 to .95. The sixth test conducted on the second red Janus(A) run resulted in a p-value equal to .11. The Wilcoxon signed ranks test failed to reject the hypothesis that is a shift in location between the field test and Janus(A) for the FSE range. Thus, there does not appear to be a shift in location when comparing the sixteen FSE ranges between the field test and the model.

The second MOP measures the association of the FSE range between the field test and Janus(A). Kendall's tau was used to test the hypothesis of no association versus the alternative that there does exist an association between the field trials and each of the three Janus(A) runs. The red force's field trial and Janus(A) FSE ranges do not appear to be associated. The hypothesis of no association was not rejected at the .10 level. The calculated correlation coefficient for the red comparisons are however positive, .309, .100, and 0. The correlation coefficient between the three red Janus(A) runs was .800 and .544, showing as expected that there is association between the Janus(A) runs when paired by scenario.

There is a positive correlation between the model and the field test's blue force FSE range. Table V shows Kendall's correlation coefficient for the blue FSE ranges, the

sample size and a significance level for each of the three runs compared to the field test. The hypothesis that there is no correlation was rejected at a significance level of .017, .067 and .007.

Table V KENDALL'S TAU COEFFICIENT FOR BLUE FORCE FSE

Kendall's Rank Correlations Blue Force				
Field	Field	Janus1	Janus2	Janus3
	1.0000	.4593	.3524	.5385
	(15)	(15)	(15)	(15)
	1.0000	.0174	.0671	.0073
Janus1	.4593	1.0000	.7782	.8804
	(15)	(16)	(16)	(16)
	.0174	1.0000	.0000	.0000
Janus2	.3524	.7782	1.0000	.7905
	(15)	(16)	(16)	(16)
	.0671	.0000	1.0000	.0000
Janus3	.5385	.8804	.7905	1.0000
	(15)	(16)	(16)	(15)
	.0073	.0000	.0000	1.0000

	Coefficient	(sample size)	significance level	

Scatter plots of both the ranked and the actual FSE range were analyzed and found to be similar. Since the FSE range data provided more information than the ranks of the FSE range, the FSE range was used to build a simple linear regression model to determine the relationship between the model and field test. Figure 2 shows the blue FSE range scatter plot with a fitted regression line and 95% confidence and prediction limits.

If the two trial, 281B and 274A are removed from the model, the model's sample coefficient of determination increases from 43.8% to 63.1%. Observations from trial 281B and 274A are labeled in the scatter plot and identified as possible outliers. In trial 281B, the blue field test's FSE range is 605 meters while the Janus(A) FSE ranges are

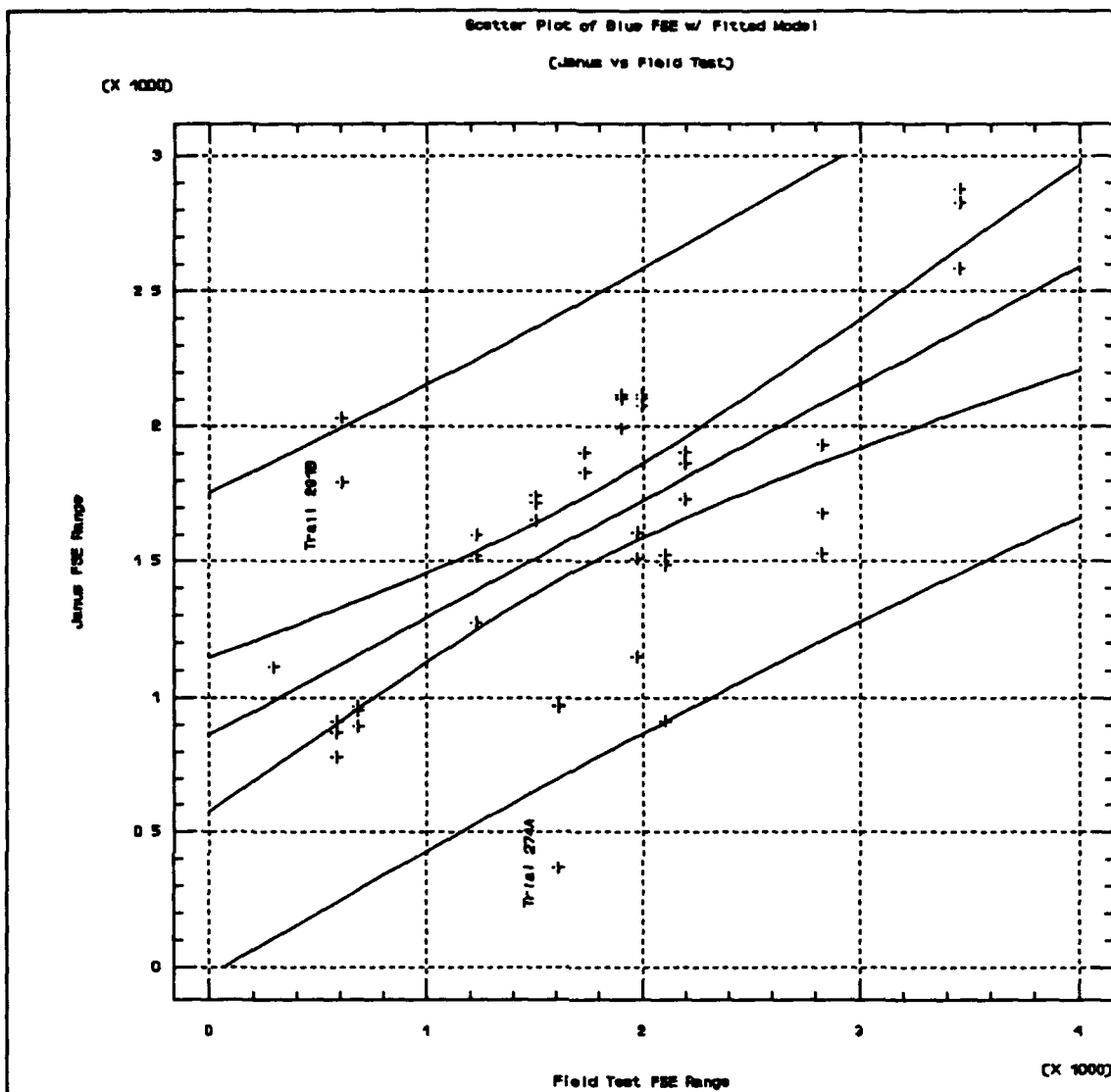


Figure 2 Blue FSE Range Scatter Plot with a Fitted Regression Line

between 1800 and 2050 meters. The red field test's FSE range is 913 meters while the Janus(A) FSE ranges are approximately 2500 meters. This indicates that LOS existed at longer ranges in Janus(A) than the field trial, assuming the field test crews engaged at the first opportunity.

However, in trial 274A, the field test showed longer engagement ranges than Janus(A). Janus(A) engaged at shorter FSE ranges. This indicates that the field test had a longer LOS range than Janus(A). The Janus(A) graphical display confirmed that the LOS ranges for the Janus(A) trial were shorter than those recorded for the field test trial.

The fitted model for the expected blue FSE range included all trials and the calculated p-values for the coefficients are less than .02. Adequacy of the model was checked using residual analysis. Visual inspection of the residual plots showed no departures from the normal, IID assumptions. The fitted regression model with the standard error in parentheses is:

$$E[FSERange] = 860 + .432 * (Field\ Test\ FSE) \\ (141) \quad (.075)$$

This model indicates that the expected Janus(A) FSE ranges are longer for those field trials with relatively short recorded FSE ranges. As the field trial's FSE range increases beyond 1500 meters, the expected Janus(A) FSE range is shorter.

The last FSE range MOP evaluates Janus(A)'s ability to accurately predict the expected field trial's FSE range using the systematically varied test factors. In the pre-test modeling phase, the modeler and operational tester are using the model to improve the test design. The model should predict the statistically significant test factors which influence the FSE range and provide insight for test design.

A regression model fitted from the Janus(A) runs was used to predict the FSE range for the field test trials. The actual field test FSE ranges were then compared to the

Janus(A) predicted FSE ranges. The regression model's response variable is the pooled Janus(A) run's FSE ranges from the different trials. The predictor variables are the three test factors and their interactions. The three test factors are at two levels, coded as a binary variable. A regression model for each side was developed using the forward selection method with variables entering the model with an F-value of 4. The regression model for the predicting FSE range for each side is:

$$E[\text{Blue FSE}] = 1820 - 614 * (\text{tank type} * \text{light condition})$$

$$\begin{aligned} E[\text{Red FSE}] &= 2431 - 927 * (\text{tactical scenario}) \\ &\quad - 775 * (\text{tank type} * \text{light}) \end{aligned}$$

The adjusted R^2 value for the two models are 17.5 and 37.2 percent. Ten of the sixteen blue force field trial recorded FSE ranges outside of a 95% confidence interval for the predicted FSE range. The red force recorded nine FSE ranges outside a 95% confidence interval for the red predicted FSE range. Over half of the field test FSE were outside of a 95% confidence level for the predicted FSE range, which suggests that Janus(A) does not accurately predict the M1A2's EUTE FSE range.

E. OPENING ROUND ENGAGEMENT ANALYSIS

1. General

Notched box-and-whisker plots were used in early exploratory data analysis to discover trends in the ORE ranges between the field test and Janus(A). In an earlier effort to compare tank first range of engagements (FREs) between Janus(A) and a

different field test, CPT Al East reported that the mean FREs are significantly higher in Janus(A) than the field test [Ref. 2:p. 31]. FRE are similar to ORE, the difference being that a weapon system may engage the same weapon system again after a specific amount of time, usually 45 seconds. His finding of longer Janus(A) engagements was not replicated in the M1A2's EUTE because the notched box-and-whisker plots of the M1A2 EUTE test and the pooled Janus(A) ORE ranges by trial showed no trends in either the median or the interquartile range. Janus(A) recorded a greater median ORE range in ten trials, eight were statistically different at a 95% confidence level. Janus(A) also showed a larger interquartile range for half of the trials when compared to the field test. The notched box-and-whisker plots for the M1A1 and M1A2 trials are in Figure 3 and Figure 4. Field trials are labeled with an 'A', Janus(A) trials with a 'J'.

The first MOP for the ORE is a comparison of the maximum ORE range, interquartile range and the median ORE range. These three statistics summarize the ORE range data. They indicate for each trial the longest direct fire LOS range (maximum range), a measure of the variance or spread in the ORE range (interquartile range), and the median range of the engagements. A large interquartile range indicated that not all systems had initial LOS in which to engage an enemy system. As forces maneuvered, additional engagement opportunities were available at closer ranges.

Since the sample data are relatively small and generally not normal, *nonparametric paired sample statistical tests* were used to test the hypothesis that there is a difference between the field test and Janus(A) based on these three summary statistics. Both the Sign and Wilcoxon signed rank tests were used to determine if a

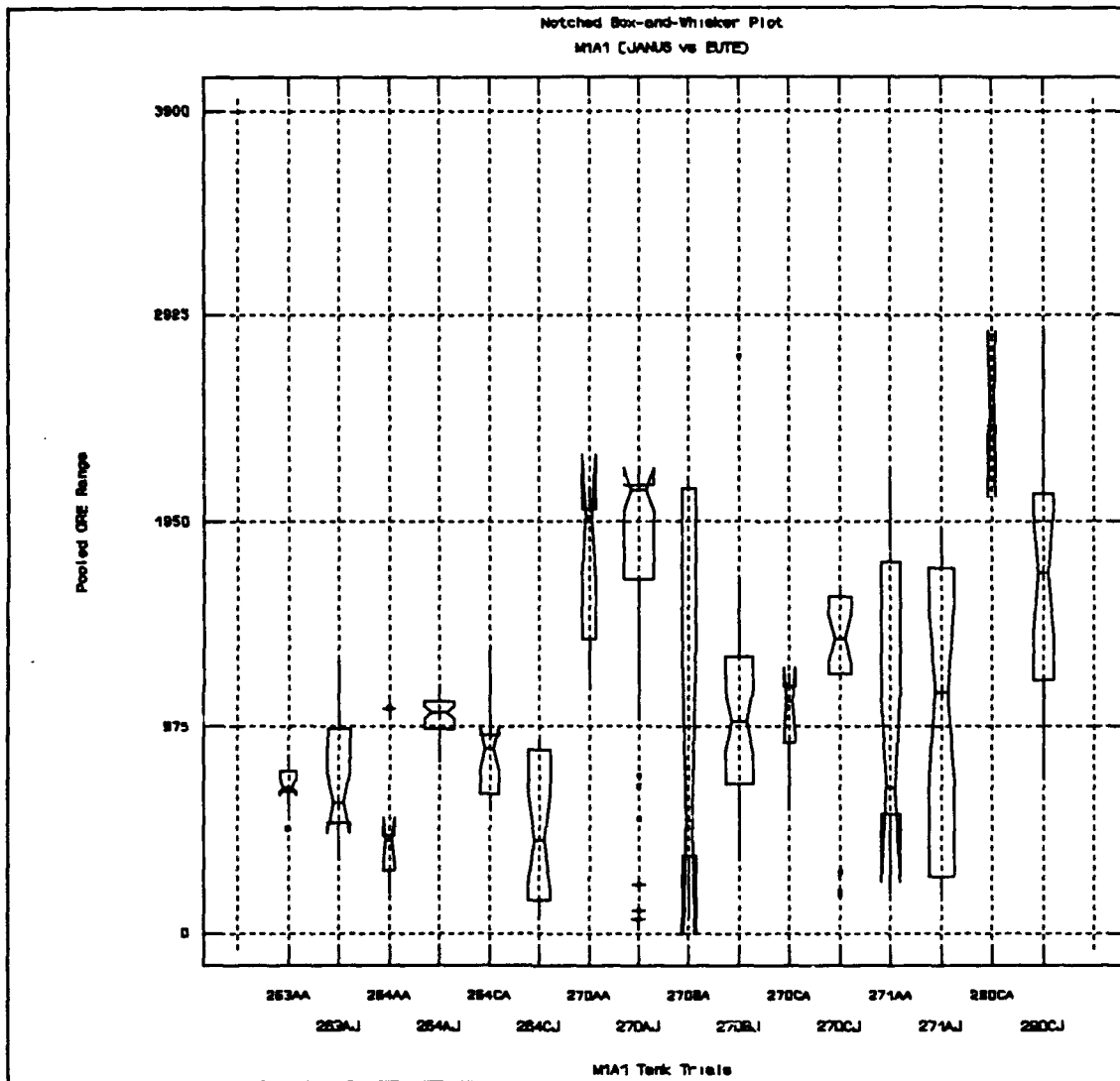


Figure 3 Comparison of M1A1 ORE Ranges

difference between the distribution of these statistics existed between the field test and the pooled Janus(A) runs. Both tests reject the hypothesis that the distribution of the maximum ORE ranges are the same for the field test and the pooled Janus(A) runs. The p-value of the Sign test is .038 and the p-value of the Wilcoxon signed rank test is .033. The two tests failed to reject the hypothesis of no difference in distribution of the interquartile ranges and the medians of the sixteen paired samples with p-values greater

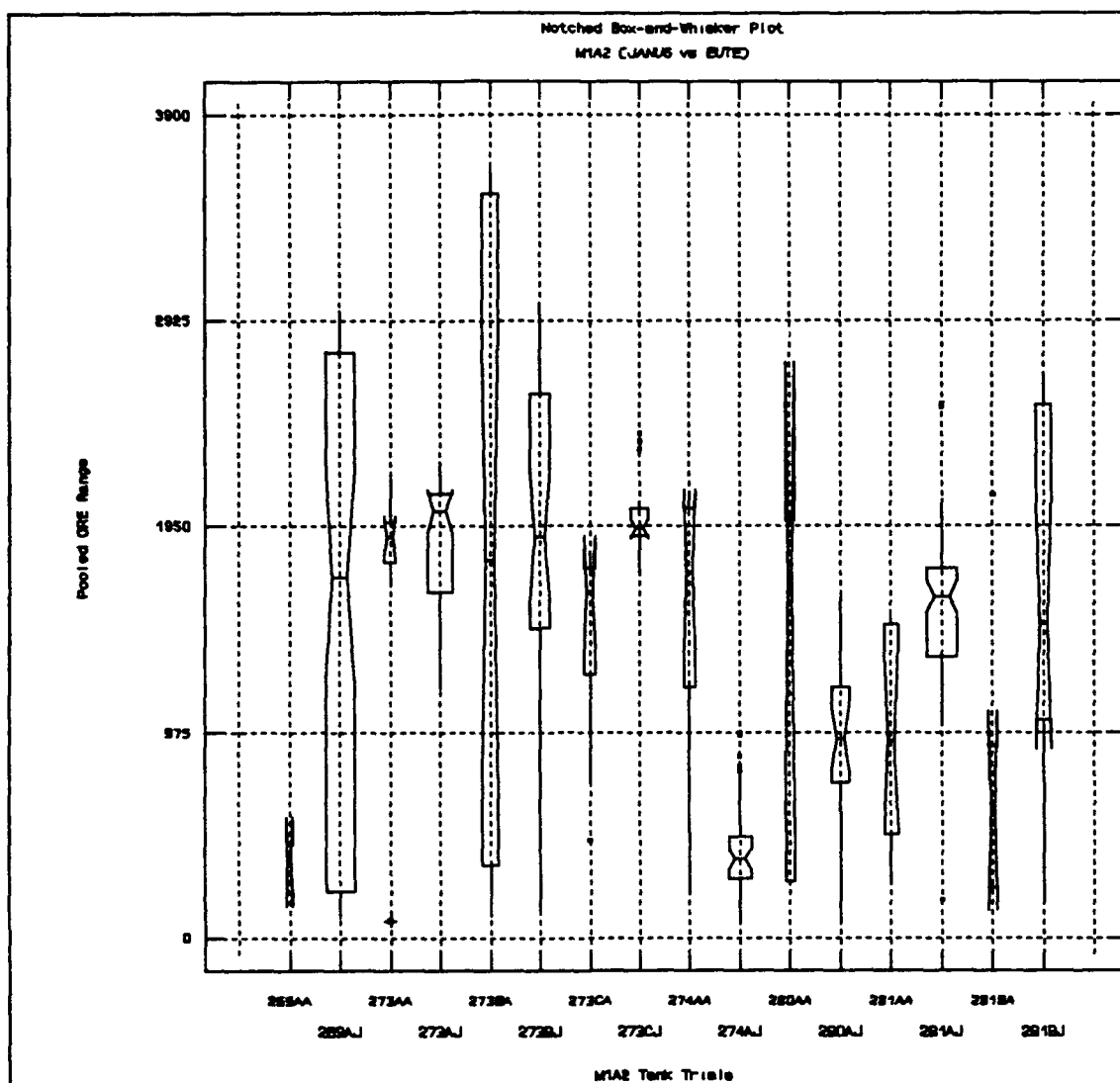


Figure 4 Comparison of M1A2 ORE Ranges

than or equal to .348 for both tests.

2. Comparison of the Distributions

The next MOP compares the distribution and medians of the ORE ranges. The Kolmogorov-Smirnov Two-Sample test was used to compare the distributions of the pooled (red and blue) ORE ranges for each field test trial to the corresponding Janus(A) runs. The test is a comparison between the empirical distribution functions of the

replicated Janus(A) runs and the field trials. Table VI contains the results of the K-S tests. The results of the K-S Two Sample Test suggest that the distribution is not the same between the field test and Janus(A). The K-S Two Sample Test rejects the hypothesis that the distributions are the same in fourteen of the sixteen comparisons. The two trials which failed to reject the hypothesis are 269A and 273A. Although the power of the test was not calculated for these trials, the number of Janus(A) observations greatly outnumbered the number of field test observations for both trials. The field trial recorded no blue engagements and only three red OREs, while Janus(A) recorded a total of sixty-six OREs. Trail 273A recorded nine field OREs and Janus(A) recorded fifty-one.

Table VI K-S TEST FOR DISTRIBUTION COMPARISON

Kolmogorov-Smirnov Two Sample Test EUTE vs Janus(A)				
Trial	P-value		Trial	P-value
263A	.0773		273A	.2570
264A	.0013		273B	.0080
264C	.0028		273C	.0019
269A	.2180		274A1	.0000
270A	.0031		280A	.0601
270B	.0174		280C	.0389
270C	.0055		281A	.0008
271A	.0924		281B	.0621

Eighty-eight percent of the trial comparisons rejected the hypothesis of equal distributions using the Kolmogorov-Smirnov Two Sample Test. These rejections are strong evidence that the field test and Janus(A) ORE range distributions are significantly different.

3. Comparison of the Medians

Although the Kolmogorov-Smirnov Two Sample Test rejected the hypothesis that the distributions are the same between the field test and Janus(A), the Mann-Whitney U test was used as an alternative two sample comparison to test whether the median ORE ranges between the field trials and Janus(A) are different. This test provides more power than the Kolmogorov-Smirnov test.

a. Separate Force ORE Ranges

The Mann-Whitney test was used to test the hypothesis that the median ORE range of red and blue forces are the same for each trial. The test rejected the hypothesis that the medians are the same in thirteen of the thirty-one comparisons. Janus(A) recorded six trials with larger median ORE ranges. Table VII shows the sample sizes and p-values for the tests. A method to combine the results of these thirty-one comparisons uses the fact that if the field trial and Janus(A) are the same, the p-values from the Mann-Whitney U test should be have a Uniform (0,1) distribution [Ref. 15]. The hypothesis that the p-values exhibit a uniform distribution was rejected using the Chi-Square Goodness-of-Fit test with three to five classes at a significance level of .000. This indicates that even though some of the individual tests

did not show a difference, there is a difference in the medians between the field test and Janus(A).

Table VII SEPARATE FORCE MEANS COMPARISON

Mann-Whitney U Test (EUTE vs Janus(A))										
Trial	Red Force		Blue Force			Trial	Red Force		Blue Force	
	Size	P-value	Size	P-value			Size	P-value	Size	P-value
263A	7/19	.1742	7/6	.1979		273A	6/23	.2582	1/22	1.00
264A	4/13	.1111	2/31	.0191		273B	5/9	.2570	17/25	.1826
264C	2/12	.2773	16/13	.0042		273C	6/17	.0003	3/4	.0323
269A	3/28	.4217				274A1	4/16	.0726	6/20	.0061
270A	9/31	.0021	2/17	.7903		280A	3/16	.0935	4/7	1.000
270B	3/9	.2286	8/33	.8693		280C	1/17	.2888	3/5	.0253
270C	5/11	.1558	2/15	.1791		281A	6/29	.0006	8/44	.0096
271A	6/6	.0247	12/25	.0442		281B	3/14	.2531	2/1	.2206

b. Pooled (Red and Blue) ORE Ranges

The Mann-Whitney U Test was also used to determine if the pooled ORE ranges were the same between the field test and Janus(A). The blue and red ORE from each trial were pooled for the test. The test rejected the hypothesis of equal medians in nine of the sixteen trials. Table VIII shows the results of the pooled Mann-Whitney U test. The Chi-Square Goodness-of-Fit test again rejected the hypothesis of a Uniform (0,1) distribution of the p-values.

Table VIII MEANS COMPARISON

Mann-Whitney U Test EUTE vs Janus(A)				
Trial	P-value		Trial	P-value
263A	.4378		273A	.4944
264A	.0026		273B	.6748
264C	.0001		273C	.0000
269A	.2568		274A1	.0002
270A	.0239		280A	.3267
270B	.3626		280C	.0519
270C	.0324		281A	.0001
271A	.5824		281B	.0614

The results of the tests show that the p-values are clustered in an interval from 0 to .25. This suggests that the median OREs are not the same for the Janus(A) and field test trials.

F. COMPARISON OF THE TEST FACTORS

The last MOP evaluated which systematic test factors; tank type, tactical posture, and light conditions, along with their interactions, are statistically significant using both the FSE and the ORE. Janus(A) and the field test's factors are then compared to determine if the same factors are significant. Both the FSE and the ORE ranges are analyzed to determine which factors are statistically significant.

The EUTE is a replicated 2^3 factorial experiment for the blue force. The red force is an unbalanced 2^3 factorial experiment with the force in an offensive tactical posture for

seventy-five percent of the trials. The red force design results in the three way interaction being confounded with the main effects. All three factors are at two levels and coded as binary variables.

Initial exploratory data analysis using the notched box plots indicated that the variances of the ORE ranges were not constant between trial, nor were the variances increasing with longer median ORE ranges. Thus, a power transformation of the ORE ranges to stabilize the variance would not have been appropriate. An alternate procedure suggested by W. J. Conover was used for the ORE ranges analysis. He suggested ranking all the observations, applying the usual analysis of variance to the ranks and then comparing this procedure to the usual analysis of variance procedure. If the two procedures give nearly identical results, then the assumptions underlying the usual analysis of variance are likely to be reasonable. If the two procedures give substantially different results, the analysis on the ranks is probably more accurate. [Ref. 16:p. 335]

1. FSE Test Factor Analysis

The usual analysis of variance procedures for both the FSE range and a ranked transformed FSE range were performed. The results of the field trial FSE range along with the significance level for the Janus(A) runs and their ranks are shown in Table IX. The blue field test showed no significant factors for either the actual or ranked FSE ranges. In the Janus(A) runs, the FSE range and the ranked FSE range analysis of variance procedure gave substantially different results. Neither the blue Janus(A) FSE nor the Janus(A) ranked FSE range indicated the same significant test factors as the field trial.

The red FSE analysis of variance provided nearly identical results for the FSE and the ranked FSE range. Thus, the underlying assumptions for the red analysis of variance seem reasonable. However, the significant test factors do not favorably compare between Janus(A) and the field test. In Janus(A), each of the main test factors were significant, while the field test ANOVA indicated that only the tank type/light condition interaction was significant. The ANOVA table for the field test indicated that the force's tactical posture was not significant, as Janus(A) indicated that the tactical posture was highly significant. The Janus(A) observation is reasonable because in the data base, there is a difference in the single shot kill probability for a stationary vehicle (defensive posture) and that for a moving vehicle.

2. ORE Test Factor Analysis

The analysis of variance for the ORE ranges for both the field test and Janus(A) was also used to compare the test factors using all the ORE ranges. Table X again shows an ANOVA table for the field test ORE ranges and the p-values for the ranked and Janus(A) ORE ranges. For the blue side, the FSE and the ranked FSE range ANOVA showed different results. Although the field test FSE ANOVA indicated that the tactical scenario and light condition interaction were significant, the ranked FSE did not. The ranked FSE indicated that the tank type and tactical scenario were significant. In the Janus(A) trials, the two procedures provided similar results, but they did not match the field trial. For the red forces, both ranked FSE range ANOVAs indicated that all second order interactions were significant, while the actual ORE ANOVA tables did not confirm this observation. Using the analysis of variance approach, it appears that Janus(A)

and the field test are different in determining which factors are important. This difference could cause the modeler and the operational tester to focus on the wrong test factors when designing an operational test.

Table IX FSE ANALYSIS OF VARIANCE TABLE

Analysis of Variance of Blue FSE Range								
Source	Sum of SQ	df	MSE	F Ratio	P-Values			
					Field	Ranked	Janus	Ranked
Tank type	342240	1	342240	0.315	.60	.90	.00	.16
Offense	402603	1	402603	0.371	.57	.59	.13	.46
Day	665858	1	665858	0.613	.46	.49	.01	.68
Tank*Offense	9706	1	9706	0.009	.92	.96	.79	.86
Tank*Day	540800	1	540800	0.498	.51	.44	.80	.00
Offense*Day	523605	1	523605	0.482	.52	.54	.02	.51
T*O*D	223112		223112	0.205	.66	.59	.64	.80
Error	7602304	7	1086043					
Total	10647612	14						

Analysis of Variance of Red FSE Range								
Source	Sum of SQ	df	MSE	F Ratio	P-Values			
					Field	Ranked	Janus	Ranked
Tank type	24245	1	24245	0.126	.73	1.00	.06	.05
Offense	102582	1	102582	0.529	.49	.56	.00	.00
Day	33973	1	33973	0.175	.69	.88	.11	.02
Tank*Offense	370481	1	370481	1.910	.20	.20	.63	.54
Tank*Day	1889323	1	1889323	9.741	.01	.00	.12	.24
Offense*Day	21717	1	21717	0.112	.75	.88	.19	.25
T*O*D	187375		187375	.996	.36	.31	.87	.57
Error	1551594	8	193494					
Total	4067634	15						

Table X ORE ANALYSIS OF VARIANCE TABLE

Analysis of Variance of Blue ORE Range								
Source	Sum of SQ	df	MSE	F Ratio	P-Values			
					Field	Ranked	Janus	Ranked
Tank type	2007802	1	2007802	2.659	.11	.40	.00	.00
Offense	2731251	1	2731251	3.617	.06	.19	.00	.00
Day	7686267	1	7686267	10.178	.00	.01	.18	.17
Tank*Offense	412573	1	412573	0.546	.47	.01	.60	.80
Tank*Day	66316	1	66316	0.088	.77	.66	.81	.11
Offense*Day	3933297	1	3933297	5.208	.02	.23	.00	.00
T*O*D	1425883		1425883	1.888	.17	.12	.19	.09
Error	64948414	86	755214					
Total	90970469	93						

Analysis of Variance of Red ORE Range								
Source	Sum of SQ	df	MSE	F Ratio	P-Values			
					Field	Ranked	Janus	Ranked
Tank type	296107	1	296107	0.834	.37	.00	.02	.00
Offense	13744185	1	13744185	3.871	.05	.00	.00	.00
Day	1046337	1	1046377	2.948	.09	.01	.66	.00
Tank*Offense	439038	1	439038	1.237	.27	.05	.54	.00
Tank*Day	5160800	1	5160800	14.538	.00	.01	.00	.00
Offense*Day	251706	1	251706	0.709	.41	.00	.65	.00
T*O*D	82223	1	82223	.232	.63	.54	.87	.00
Error	23784213	67	354988					
Total	33992125	74						

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

A general overview of the FSE ranges from the Janus(A) simulation model compared to an actual field test's FSE ranges indicates that they are similar. There is a positive correlation between the simulation model's blue FSE range to those FSE ranges recorded during the field test. A paired sample comparison using nonparametric tests indicates no difference in the spread and median of the FSE range between the field test and Janus(A). However, as the detail of the comparison increases, we see the model's ability to replicate the ranges of the field test weaken. There is statistical evidence indicating that the model's ORE ranges do not adequately replicate the M1A2's ORE ranges from the September 1991 EUTE trials.

A comparison of the empirical ORE range distribution from fourteen of the sixteen trials showed statistical differences. A comparison of the median ORE range also showed that the majority of the trials do not have statistically equal medians. In addition, there is an indication that the main and interaction effects of the EUTE's test factors for both the ORE and FSE range are different than those predicted from the model. Thus, judging from the September 1991 trial, the Janus(A) should not be accredited for post-test modeling of the M1A2 EUTE.

B. RECOMMENDATIONS

1. Janus(A)

The analysis of the FSE and ORE ranges for the sixteen trials indicates that engagement opportunities differ for the model and the field test, depending upon the terrain. In numerous trials Janus(A) generated longer engagement ranges than the field test, while other trials showed that the field trial produced longer engagement ranges. Since the engagement opportunities in Janus(A) are dependent upon the line of sight between the opposing forces, the 50 meter resolution Janus(A) terrain database may not be adequate for model accreditation. Further investigation of a higher resolution terrain database is recommended.

The CITV algorithm was developed for the M1A2 post-test modeling effort without the benefit of an external validation or verification process. How well this algorithm models the CITV probably warrants additional investigation.

2. Field Test Data

The field test data contained several engagements of an unknown range and battles with limited engagement ranges. This trend was apparent in all trials and may bias the field test data. Improvements to capture all field test engagement ranges are necessary for a more accurate comparison of the model and field tests.

Although not considered in the comparison, the field test experienced both M1A2 mechanical problems and software upgrades inherent in many new weapon systems. These problems must have affected the crew's ability to effectively operate and

employ the enhancements provided by the M1A2. These hardware problems coupled with the learning curve associated with a high technology advanced weapon system were not incorporated into Janus(A). Between the September trial and December trials, the reliability of the weapon system improved and the rotated crew training was not as disturbed. The results from the December trial should provide a more accurate representation of the weapon system with a highly trained crew. This thesis recommends that the December 1991 trials be analyzed to aid the post-test modeling accreditation effort.

APPENDIX A: PLS CONVERSION PROGRAM

```

PROGRAM PLSTRN

*   THIS PROGRAM TAKES THE TEC POSITION LOCATION DATA WHICH
*   IS BY SECOND AND EXTRACTS EVERY MINUTE FOR JANUS USE.
*   THE FILE CHRONORD.DAT IS CREATED TO STORE THE INFORMATION.

INTEGER SS, X, Y, NUMVEH, I, COUNT, BUFFER(65,2), XDEFLT, YDEFLT
INTEGER CITV, K
CHARACTER PID*4, TIME*5, FILE*16, PIDBUF(65)*4, TIMBUF*6, ID(4)*4
LOGICAL MISSED, WITH
COMMON NUMVEH

XDEFLT = 55000
YDEFLT = 78000
WITH = .FALSE.
ID(1) = 'PT99'
ID(2) = 'PT98'
ID(3) = 'PT97'
ID(4) = 'PT96'
K = 1

PRINT *, 'INPUT FILE (EG 264C.PLS) ? (USE APOSTROPHES)'
READ *, FILE
FILE = '[.M1A2]' // FILE
OPEN(UNIT=10, FILE=FILE, STATUS='OLD', RECL=32,
1  CARRIAGECONTROL='LIST')
PRINT *, FILE

PRINT *, 'ENTER TOTAL # OF VEHICLES (INCL AIRCRAFT) IN TRIAL'
PRINT *, 'TRIAL 264C IS 16'
PRINT *, 'TRIAL 271A IS 14'
PRINT *, 'TRIAL 273B IS 12'
PRINT *, 'TRIAL 273C IS 6'

READ *, NUMVEH
PRINT *, 'ENTER THE NUMBER OF M1A2 WITH CITV'
READ *, CITV
PRINT *, 'PROGRAM CONTINUING...'

OPEN(UNIT=11, FILE='CHRONORD.HLP', STATUS='NEW'
C, FORM='FORMATTED')
5  READ(10,10,END=30) PID, TIME, SS, X, Y
10 FORMAT(7X,A4,1X,A5,1X,I2,1X,I5,1X,I5)

IF(SS.EQ.0.) THEN
  IF(X.NE.0) THEN
    IF(PID(:2).NE.'HD') THEN
      IF(PID(:2).EQ.'PT') THEN
        WRITE(11,20) TIME, ID(K), XDEFLT, YDEFLT
        IF(K.LT.CITV) THEN
          K = K+1
        ELSE
          K=1
        ENDIF
      ENDIF
      WRITE(11,20) TIME, PID, X, Y
    ENDIF
  ENDIF
ENDIF

20 FORMAT(1X,A5,':00',2X,A4,2X,I5,2X,I5)
GO TO 5

```

```

30 CONTINUE
CLOSE(UNIT=10)
CLOSE(UNIT=11)

NUMVEH = NUMVEH + CITV

PRINT*, 'FINISHED CONVERTING PLS'
PRINT*, 'PROGRAM CONTINUING...'
OPEN(UNIT=12, FILE = 'CHRONORD.DAT', STATUS='NEW')
OPEN(UNIT=11, FILE = 'CHRONORD.HLP', STATUS='OLD')
DO 13 I=1, NUMVEH
  READ(11,*) TIME, PID, X, Y
  FORMAT(1X,A5,5X,A4,2X,I5,2X,I5)
  PIDBUF(I) = PID
  BUFFER(1,1) = X
  BUFFER(1,2) = Y
  TIMBUF = TIME
  WRITE(12,20) TIME, PID, X, Y
13 CONTINUE

COUNT = 1
6 READ(11,9,END=31) TIME, PID, X, Y
9 FORMAT(1X,A5,5X,A4,2X,I5,2X,I5)
2 CONTINUE
  MISSED = .FALSE.
  IF(PID.EQ.PIDBUF(COUNT)) THEN
    BUFFER(COUNT,1) = X
    BUFFER(COUNT,2) = Y
    TIMBUF = TIME
    WRITE(12,20) TIME, PID, X, Y
  ELSE
    MISSED = .TRUE.
    PRINT*, 'OUT OF SEQUENCE AT ', TIME, ' ', PID
    WRITE(12,20) TIMBUF, PIDBUF(COUNT),
C    BUFFER(COUNT,1), BUFFER(COUNT,2)
  ENDIF
  COUNT = COUNT + 1
  IF(COUNT.EQ.NUMVEH+1) COUNT = 1
  IF(MISSED) GO TO 2
GO TO 6
31 CONTINUE
CLOSE(UNIT=11)
CLOSE(UNIT=12)

CALL FOURFILE

STOP
END

SUBROUTINE FOURFILE
* (WRITTEN BY CPT AL EAST, MODIFIED BY CPT AL VIANA)

* THIS SUBROUTINE CREATES FOUR FILES
* (NTCMOVE999.DAT, NTCROUT999.DAT, NTCPLAY999.DAT, NTCKILS999.DAT)
* WHICH ARE USED BY INITNTC TO RUN JANUS
* ADDITIONALLY, BADGRID999.DAT CONTAINS ALL THE GRIDS FROM
* THE TRIAL THAT WILL NOT FIT ON A 50X50 JANUS MAP.

INTEGER LPN, X, Y, NTCTYPE, I, NUMVEH, J
CHARACTER DATE*9, TIME*8, TECTYPE*2, SIDE*1, PID*3, BOGUS*64
LOGICAL WRITEPLAY

COMMON NUMVEH

OPEN(UNIT=10, FILE='NTCROUT999.DAT', STATUS='NEW')
OPEN(UNIT=11, FILE='NTCMOVE999.DAT', STATUS='NEW')
OPEN(UNIT=36, FILE='NTCPLAY999.DAT', STATUS='NEW')
OPEN(UNIT=37, FILE='NTCKILS999.DAT', STATUS='NEW')

OPEN(UNIT=14, FILE='BADGRID999.DAT', STATUS='NEW')

```

```

WRITE(14,*) 'THESE GRIDS HAVE BEEN DELETED SINCE '
WRITE(14,*) 'THEY DO NOT FIT ON A 50X50 JANUS MAP...'
WRITE(14,*) ' '

```

C NTCMOVE999.DAT USES CHRONORD.DAT

```

OPEN(UNIT=13,FILE='CHRONORD.DAT',STATUS='OLD')
WRITE(10,*) ' '
WRITE(11,*) ' '
WRITE(36,*) ' '
WRITE(37,*) ' '
WRITE(10,*) 'routs_all table'
WRITE(11,*) 'move_all table'
WRITE(36,*) 'pdscr table'
WRITE(37,*) 'kills_all table'
WRITE(10,*) ' '
WRITE(11,*) ' '
WRITE(36,*) ' '
WRITE(37,*) ' '
WRITE(10,1)
WRITE(11,1)
1 FORMAT('time',16X,':lpn ',2X,':side',2X,':pid',3X,':',
C'ptype',1X,':x',4X,':y',5X,':')
WRITE(10,2)
WRITE(11,2)
2 FORMAT(':-:-----:-----:-----:-----:-----:',
C'-----:-----:')
WRITE(36,33)
WRITE(37,34)
33 FORMAT(':lpn',3X,':pid',3X,':side',2X,':org',17X,':ptype ')
34 FORMAT(':tlpn',1X,':tpid',1X,':side',1X,':result',':time',16X
C':tx',3X,':ty',3X,':flpn',2X,':fpid',2X,':fwpn',2X,':fx',3X
C':fy',3X,':fy',3X,':frat :')
WRITE(36,*) ' '
WRITE(37,*) ' '

DATE='12 APR 92'

```

C*****CREATING NTCMOVE999.DAT*****

```

LPN=0
7 LPN=LPN+1
IF (LPN.EQ.NUMVEH+1) LPN=1
READ(13,20,END=40) TIME,TECTYPE,PID,X,Y

10 CONTINUE
IF (TECTYPE.EQ.'AH') THEN
    NTCTYPE=22
    SIDE='B'
ELSEIF (TECTYPE.EQ.'HD') THEN
    NTCTYPE=22
    SIDE='O'
ELSEIF (TECTYPE.EQ.'BR') THEN
    NTCTYPE=29
    SIDE='B'
* DIFFERENT TYPES OF US TANKS
ELSEIF (TECTYPE.EQ.'FT') THEN
    NTCTYPE=1
    SIDE='B'
ELSEIF (TECTYPE.EQ.'PT') THEN
    NTCTYPE=1
    SIDE='B'
ELSEIF (TECTYPE.EQ.'A2') THEN
    NTCTYPE=1
    SIDE='B'
ELSEIF (TECTYPE.EQ.'A0') THEN
    NTCTYPE=1
    SIDE='B'

ELSEIF (TECTYPE.EQ.'LO') THEN

```

```

        NTCTYPE=10
        SIDE='B'
    ELSEIF (TECTYPE.EQ.'OH') THEN
        NTCTYPE=26
        SIDE='B'
    ELSEIF (TECTYPE.EQ.'CC') THEN
        NTCTYPE=14
        SIDE='B'
    ELSEIF (TECTYPE.EQ.'AG') THEN
        NTCTYPE=25
        SIDE='B'
    ELSEIF (TECTYPE.EQ.'BM') THEN
        NTCTYPE=3
        SIDE='O'
    ELSEIF (TECTYPE.EQ.'HP') THEN
        NTCTYPE=27
        SIDE='O'
    ELSEIF (TECTYPE.EQ.'TT') THEN
        NTCTYPE=1
        SIDE='O'
    ELSEIF (TECTYPE.EQ.'TV') THEN
        NTCTYPE=20
        SIDE='O'
    ELSEIF (TECTYPE.EQ.'FF') THEN
        NTCTYPE=25
        SIDE='O'
    ELSEIF (TECTYPE.EQ.'TH' ) THEN
        NTCTYPE=23
        SIDE='O'
    ELSE
        PRINT*, '*****'
        PRINT*, 'DO NOT HAVE A NTCTYPE MATCH FOR TECTYPE ', TECTYPE
        PRINT*, 'HAVE ASSIGNED IT A NTCTYPE OF 0 (ZERO) AND PUT ON'
        PRINT*, 'THE BLUE SIDE'
        PRINT*, '*****'
        PRINT*, 'PROGRAM CONTINUING.....'
        NTCTYPE=0
        SIDE='B'
    ENDIF

    IF ((X.GT.50000.AND.X.LT.65000).AND.(Y.GT.73000
C .AND.Y.LT.88000)) THEN
        WRITE(11,30) DATE, TIME, LPN, SIDE, PID, NTCTYPE, X, Y
    ELSE
        WRITE (14,20) TIME, TECTYPE, PID, X, Y
    ENDIF

    GO TO 7

20  FORMAT(1X,A8,2X,A2,A3,1X,I5,2X,I5)
30  FORMAT(' ',A9,1X,A8,' ',I3,3X,' ',A1,5X,' ',A3,3X,' ',I2
C,4X,' ',I5,' ',I5,' ')

40  CONTINUE

    CLOSE(UNIT=11)
    CLOSE(UNIT=13)
    CLOSE(UNIT=14)

    OPEN(UNIT=81, FILE='NTCMOVE999.DAT', STATUS='OLD')
    I=1

95  DO 76 J=1,5
        READ(81,82) BOGUS
82  FORMAT(1X,A64)
76  CONTINUE

    WRITEPLAY=.TRUE.
83  READ(81,84,END=66) DATE, TIME, LPN, SIDE, PID, NTCTYPE, X, Y
84  FORMAT(2X,A9,1X,A8,2X,I3,4X,A1,6X,A3,4X,I2,5X,I5,2X,I5)
    IF (LPN.EQ.I) THEN

```

```

        WRITE(10,30) DATE, TIME, LPN, SIDE, PID, NTCTYPE, X, Y
        IF(WRITEPLAY) THEN
            WRITE(36,85) LPN, PID, SIDE, NTCTYPE
            WRITEPLAY=.FALSE.
        ENDIF
    ENDIF
    GO TO 83
66  CLOSE(UNIT=81)
    OPEN(UNIT=81, FILE='NTCMOVE999.DAT', STATUS='OLD')

85  FORMAT(' ', I3, 3X, ' ', A3, 3X, ' ', A1, 5X, ' ', 20X, ' ', I2, 4X
C, ' ')

    I=I+1

    IF(I.EQ.NUMVEH+1) GO TO 99
    GO TO 95

99  CONTINUE
    WRITE(10,2)
    WRITE(37,*) ' '
    WRITE(37,98)
98  FORMAT(' :-----'
C, '-----: ')

    RETURN
    END

```


APPENDIX B: ORE EXTRACTION PROGRAMS

```

*****
*                               ACQ2.FOR                               *
*****

PROGRAM OMS_ENGRNG

* PROGRAM OBTAINS THE ENGAGEMENT RANGE FROM THE OMS TRIALS
  INTEGER ENGRNG
  CHARACTER TRIAL*6, INFILE*10, OUTFIL*9,OUTFILE*8,BID*2,EXPER*9
  CHARACTER TIME*5, TTYPE*1, BTYPE*1, BWP*6, RWP*6,TID*2

  PRINT *, ' INPUT THE FILE (IE OMS1A1.RED) '
  READ *, INFILE
  OUTFILE = INFILE
  OUTFIL = INFILE

  OPEN(UNIT=10, FILE = INFILE, MODE='READ')
  OPEN(UNIT=11, FILE= OUTFILE, MODE='WRITE')
  IF(INFILE(8:10).EQ.'RED'.OR.INFILE(8:10).EQ.'red') THEN

5  READ(10,10,END=30) TRIAL, TTYPE, TID, BTYPE, BID, TIME, ENGRNG
10  FORMAT(17X,A6,1X,A1,1X,A2,22X,A1,1X,A2,84X,A5,112X,I5)

    IF(ENGRNG.GT.4500) ENGRNG = 0
    IF(TTYPE.NE.'H') THEN
      IF(BTYPE.EQ.'A') BWP = 'BTANK1'
      IF(BTYPE.EQ.'P') BWP = 'BTANK2'
      IF(TTYPE.EQ.'B') RWP = 'RAPC4'
      IF(TTYPE.EQ.'T') RWP = 'RTANK1'

      IF(TRIAL.EQ.'263A ') EXPER = ' 1 1 1'
      IF(TRIAL.EQ.'264A ') EXPER = ' 1 1 1'
      IF(TRIAL.EQ.'270B ') EXPER = ' 1 1 1'
      IF(TRIAL.EQ.'270C ') EXPER = ' 1 0 1'
      IF(TRIAL.EQ.'273B ') EXPER = ' 0 1 0'
      IF(TRIAL.EQ.'280A ') EXPER = ' 0 1 1'
      IF(TRIAL.EQ.'281A ') EXPER = ' 0 1 1'
      IF(TRIAL.EQ.'273C ') EXPER = ' 0 0 1'
      IF(TRIAL.EQ.'264C ') EXPER = ' 1 1 0'
      IF(TRIAL.EQ.'270A ') EXPER = ' 1 1 0'
      IF(TRIAL.EQ.'271A ') EXPER = ' 1 1 0'
      IF(TRIAL.EQ.'280C ') EXPER = ' 1 0 0'
      IF(TRIAL.EQ.'269A ') EXPER = ' 0 1 0'
      IF(TRIAL.EQ.'273A ') EXPER = ' 0 1 1'
      IF(TRIAL.EQ.'274A1 ') EXPER = ' 0 1 0'
      IF(TRIAL.EQ.'281B ') EXPER = ' 0 0 0'

      IF(ENGRNG.NE.0.AND.TIME.NE.'00:00') THEN
        WRITE(11,20) TIME, TID, ' RED',RWP,BID,BWP,REAL(ENGRNG)/1000
C      ,TRIAL,'A',EXPER
      ENDIF
20  FORMAT(2X,A5,6X,A2,3X,A4,3X,A6,15X,A2,10X,A6,35X,F5.3,1X,A4,A1
C      ,A9)
      ENDIF
      GO TO 5

30  CONTINUE

    ELSE
      6  READ(10,11,END=31) TRIAL, TIME, BTYPE, BID, TTYPE, TID, ENGRNG
      11  FORMAT(17X,A6,271X,A5,1X,A1,1X,A2,43X,A1,1X,A2,27X,I5)

```

```

IF(ENGRNG.GT.4500) ENGRNG = 0
IF(TTYPE.NE.'H') THEN
  IF(BTYPE.EQ.'A') BWPN = 'BTANK1'
  IF(BTYPE.EQ.'P') BWPN = 'BTANK2'
  IF(TTYPE.EQ.'B') RWPN = 'RAPC4'
  IF(TTYPE.EQ.'T') RWPN = 'RTANK1'
  PRINT*, 'TTYPE', TTYPE
  PRINT*, 'BTYPE', BTYPE
  PRINT*, 'ENGRNG', ENGRNG

  IF(TRIAL.EQ.'263A ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'264A ') EXPER = ' 1 0 1'
  IF(TRIAL.EQ.'270B ') EXPER = ' 1 0 1'
  IF(TRIAL.EQ.'270C ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'273B ') EXPER = ' 0 1 0'
  IF(TRIAL.EQ.'280A ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'281A ') EXPER = ' 0 0 1'
  IF(TRIAL.EQ.'273C ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'264C ') EXPER = ' 1 0 0'
  IF(TRIAL.EQ.'270A ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'271A ') EXPER = ' 1 0 0'
  IF(TRIAL.EQ.'280C ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'269A ') EXPER = ' 0 0 0'
  IF(TRIAL.EQ.'273A ') EXPER = ' 0 0 1'
  IF(TRIAL.EQ.'274A1 ') EXPER = ' 0 0 0'
  IF(TRIAL.EQ.'281B ') EXPER = ' 0 1 0'

  IF(ENGRNG.NE.0.AND.TIME.NE.'00:00') THEN
    WRITE(11,21) TIME, BID, 'BLUE', BWPN, TID, RWPN, REAL(ENGRNG)/1000
  C   , TRIAL, 'A', EXPER
    ENDIF
  ENDIF
21  FORMAT(2X,A5,6X,A2,3X,A4,3X,A6,15X,A2,10X,A6,35X,F5.3,1X,A4,A1
  C   ,A9)

  GO TO 6

31  CONTINUE

  ENDIF

  CLOSE (UNIT=10)
  CLOSE (UNIT=11)

  PRINT*, 'FINISHED'
  STOP
  END

*****
*                               FLD.FOR                               *
*****

PROGRAM FIELD_ORE

* THE PROGRAM WILL DETERMINE THE OPENING ROUND ENGAGEMENTS
* FROM A FORMATED ASCII FILE

INTEGER MTR(66,66,2), FID, TID, I, O, D, T
REAL ENGRNG, TIME, OLDTIM
CHARACTER SIDE*4, WPN*6, INFILE*8, TRIAL*5, OLDTRL*5, TWPN*6
I = 1
OLDTIM = 0.0

CALL CLEAR(MTR)

PRINT *, ' INPUT THE FILE (IE DATA.FLD) '
READ *, INFILE

OPEN(UNIT=10, FILE = INFILE, MODE='READ')
OPEN(UNIT=11, FILE='BSHOTA.DAT', MODE='WRITE')

```

```

OPEN(UNIT=12, FILE='BFRSTA.DAT', MODE='WRITE')
OPEN(UNIT=13, FILE='RSHOTA.DAT', MODE='WRITE')
OPEN(UNIT=14, FILE='RFRSTA.DAT', MODE='WRITE')

5  READ(10,10,END=30) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG,TRIAL,T,O,D
10  FORMAT(1X,F5.2,3X,I2,1X,A4,1X,A6,3X,I2,1X,A6,1X,F5.3,1X,A5,4X,
C   I1,5X,I1,5X,I1)

      IF(I.EQ.1) OLDTRL = TRIAL

      IF(TRIAL.NE.OLDTRL) THEN
        CALL CLEAR(MTR)
        PRINT*, 'THE OLD TRIAL IS ', OLDTRL
        PRINT*, 'THE NEW TRIAL IS ', TRIAL
      ENDIF
      OLDTRL = TRIAL

*      IF(TIME.LT.OLDTIM) THEN
*        CALL CLEAR(MTR)
*      ENDIF
*      OLDTIM = TIME

      IF(SIDE.EQ.'BLUE') THEN
        IF(MTR(FID,TID,1).EQ.0) THEN
          MTR(FID,TID,1) = 1
          WRITE(11,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
            ,T,O,D
          IF(MTR(TID,FID,2).EQ.0) THEN
            WRITE(12,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
              ,T,O,D
          ENDIF
        ELSE
          IF(MTR(FID,TID,2).EQ.0) THEN
            MTR(FID,TID,2) = 1
            WRITE(13,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
              ,T,O,D
            IF(MTR(TID,FID,1).EQ.0) THEN
              WRITE(14,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
                ,T,O,D
            ENDIF
          ENDIF
        ENDIF
      ENDIF

20  FORMAT(1X,F5.2,3X,I2,3X,A4,2X,A6,2X,I2,3X,A6,2X,F5.0,3X,A5,2X,
C   I1,2X,I1,2X,I1)

      I=2
      GO TO 5

30  CONTINUE
      CLOSE (UNIT=10)
      CLOSE (UNIT=11)
      CLOSE (UNIT=12)
      CLOSE (UNIT=13)
      CLOSE (UNIT=14)

      PRINT*, 'FINISHED'
      STOP
      END

      SUBROUTINE CLEAR(MTR)

      INTEGER I,J,K, MTR(66,66,2)
      PRINT*, 'CLEARING THE MATRIX'

      DO 10 I=1,66
        DO 20 J=1,66
          DO 30 K=1,2
            MTR(I,J,K) = 0
          30  CONTINUE
        20  CONTINUE
      10  CONTINUE

```

```

10 CONTINUE
   RETURN
   STOP
   END

```

```

* *****
* *                               JANUS.FOR                               *
* *****

```

```
PROGRAM JANUS_ORE
```

```

INTEGER MTR(66,66,2), FID, TID, I
REAL ENGRNG, TIME, OLDTIM
CHARACTER SIDE*4, WPN*6, INFILE*8, TRIAL*5, OLDTRL*5, TWPN*6
CHARACTER EXPER*9
I = 1
OLDTIM = 0.0

```

```

PRINT *, ' INPUT THE FILE (IE DATA.JNS) '
READ *, INFILE

```

```

OPEN(UNIT=10, FILE = INFILE, MODE='READ')
OPEN(UNIT=11, FILE='BSHOTJ.DAT', MODE='WRITE')
OPEN(UNIT=12, FILE='BFRSTJ.DAT', MODE='WRITE')
OPEN(UNIT=13, FILE='RSHOTJ.DAT', MODE='WRITE')
OPEN(UNIT=14, FILE='RFRSTJ.DAT', MODE='WRITE')

```

```

5 READ(10,10,END=30)TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG,TRIAL
10 FORMAT(2X,F5.2,6X,I1,4X,A4,3X,A6,15X,I1,11X,A6,35X,F5.3,1X,A5)

```

```

IF(SIDE.EQ.'BLUE') THEN
  IF(TRIAL.EQ.'263AJ ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'264AJ ') EXPER = ' 1 0 1'
  IF(TRIAL.EQ.'270BJ ') EXPER = ' 1 0 1'
  IF(TRIAL.EQ.'270CJ ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'273BJ ') EXPER = ' 0 1 0'
  IF(TRIAL.EQ.'280AJ ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'281AJ ') EXPER = ' 0 0 1'
  IF(TRIAL.EQ.'273CJ ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'264CJ ') EXPER = ' 1 0 0'
  IF(TRIAL.EQ.'270AJ ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'271AJ ') EXPER = ' 1 0 0'
  IF(TRIAL.EQ.'280CJ ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'269AJ ') EXPER = ' 0 0 0'
  IF(TRIAL.EQ.'273AJ ') EXPER = ' 0 0 1'
  IF(TRIAL.EQ.'274XJ ') EXPER = ' 0 0 0'
  IF(TRIAL.EQ.'281BJ ') EXPER = ' 0 1 0'
ELSE
  IF(TRIAL.EQ.'263AJ ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'264AJ ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'270BJ ') EXPER = ' 1 1 1'
  IF(TRIAL.EQ.'270CJ ') EXPER = ' 1 0 1'
  IF(TRIAL.EQ.'273BJ ') EXPER = ' 0 0 0'
  IF(TRIAL.EQ.'280AJ ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'281AJ ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'273CJ ') EXPER = ' 0 0 1'
  IF(TRIAL.EQ.'264CJ ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'270AJ ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'271AJ ') EXPER = ' 1 1 0'
  IF(TRIAL.EQ.'280CJ ') EXPER = ' 1 0 0'
  IF(TRIAL.EQ.'269AJ ') EXPER = ' 0 1 0'
  IF(TRIAL.EQ.'273AJ ') EXPER = ' 0 1 1'
  IF(TRIAL.EQ.'274AJ ') EXPER = ' 0 1 0'
  IF(TRIAL.EQ.'274XJ ') EXPER = ' 0 1 0'
  IF(TRIAL.EQ.'281BJ ') EXPER = ' 0 0 0'
ENDIF

```

```
IF(I.EQ.1) OLDTRL = TRIAL
```

```
IF(TRIAL.NE.OLDTRL) THEN
```

```

        CALL CLEAR(MTR)
        PRINT*, 'THE OLD TRIAL IS ', OLDTRL
        PRINT*, 'THE NEW TRIAL IS ', TRIAL
    ENDIF
    OLDTRL = TRIAL

    IF (TIME.LT.OLDTIM) THEN
        CALL CLEAR(MTR)
    ENDIF
    OLDTIM = TIME

    IF (SIDE.EQ.'BLUE') THEN
        IF (MTR(FID,TID,1).EQ.0) THEN
            MTR(FID,TID,1) = 1
            WRITE(11,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
C            ,EXPER
            IF (MTR(TID,FID,2).EQ.0) THEN
                WRITE(12,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
C            ,EXPER
            ENDIF
        ENDIF
    ELSE
        IF (MTR(FID,TID,2).EQ.0) THEN
            MTR(FID,TID,2) = 1
            WRITE(13,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
C            ,EXPER
            IF (MTR(TID,FID,1).EQ.0) THEN
                WRITE(14,20) TIME,FID,SIDE,WPN,TID,TWPN,ENGRNG*1000,TRIAL
C            ,EXPER
            ENDIF
        ENDIF
    ENDIF

20    FORMAT(1X,F5.2,3X,I2,3X,A4,2X,A6,2X,I2,3X,A6,2X,F5.0,3X,A5
C        ,A9)

    I=2
    GO TO 5

30    CONTINUE
    CLOSE (UNIT=10)
    CLOSE (UNIT=11)
    CLOSE (UNIT=12)
    CLOSE (UNIT=13)
    CLOSE (UNIT=14)

    PRINT*, 'FINISHED'
    STOP
    END

    SUBROUTINE CLEAR(MTR)

        INTEGER I,J,K, MTR(66,66,2)
        PRINT*, 'CLEARING THE MATRIX'

        DO 10 I=1,66
            DO 20 J=1,66
                DO 30 K=1,2
                    MTR(I,J,K) = 0
30                CONTINUE
20            CONTINUE
10        CONTINUE
        RETURN
        STOP
        END

```

APPENDIX C: LIST OF ACRONYMS

BMP	Soviet Mechanized Infantry Vehicle
CITV	Commanders Independent Thermal Viewer
EUTE	Early Users Test and Experimentation
FDTE	Force Development Test and Experimentation
FHL	Fort Hunter Liggett
FORTTRAN	Formula Translation Computer Language
FRE	First Round Engagement
FSE	First Shot Engagement
FST	Future Soviet Tank
INITNTC	Program to convert NTC battles to Janus format
IOT	Initial Operational Test
LOS	Line of Sight
M1A1/M1A2	US Army Abrams tank
MOP	Measure of Performance
M-T-M	Model-Test-Model
NVEOL	Night Vision Electro Optical Laboratory
OMS	Operational Mode Summary
OPTEC	Operational Test and Evaluation Command
ORE	Opening Round Engagement

PLS	Position Location System
RMS	Range Measuring System
SME	Subject Matter Experts
TEC	TEXCOM Experimentation Center
TEXCOM	Testing and Experimentation Command
TRAC	Training and Doctrine Analysis Command

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